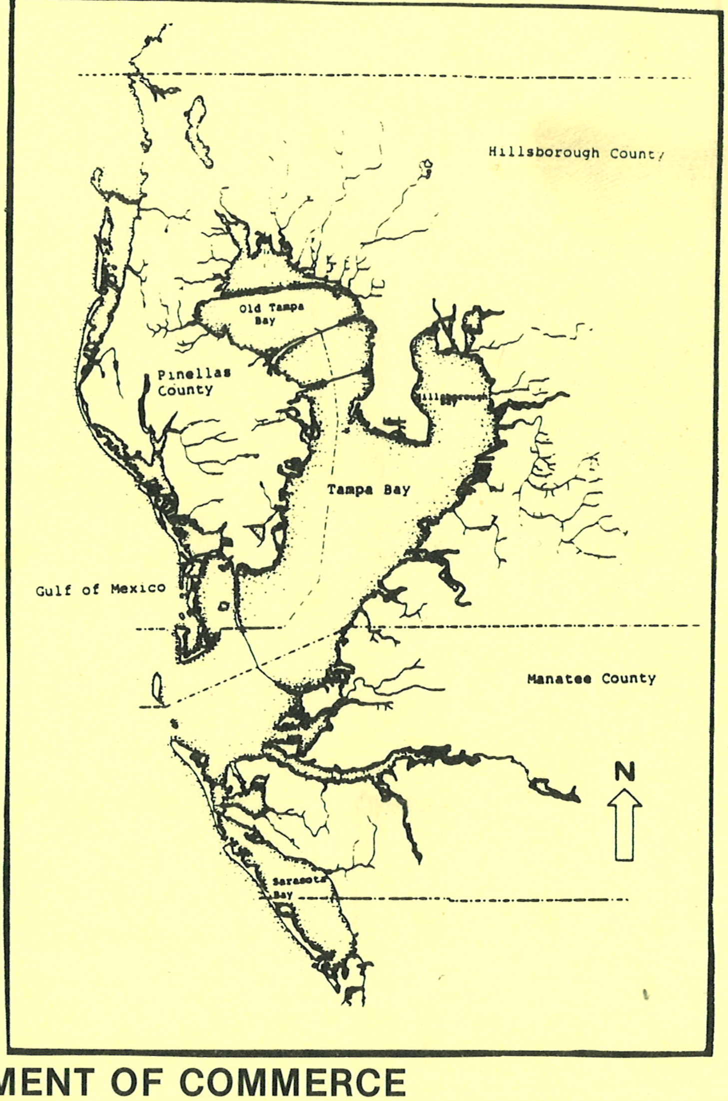
NOAA Estuary-of-the-Month

Seminar Series NO. 11

Tampa and Sarasota Bays: Issues, Resources, Status, and Management

February 1989



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NOAA Estuarine Programs Office

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Proceedings of a Seminar
Held December 10, 1987
Washington, D.C.

U.S. DEPARTMENT OF COMMERCE
C. William Verity, Secretary

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TAMPA AND SARASOTA BAYS: ISSUES, RESOURCES, STATUS, AND MANAGEMENT

Edited by Ernest D. Estevez

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PREFACE

The following are the proceedings of a seminar on Tampa and Sarasota Bays held on December 10, 1987 at the Herbert C. Hoover Building of the U.S. Department of Commerce in Washington, D.C. The Estuarine Programs Office (EPO) of the National Oceanic and Atmospheric Administration sponsored this seminar as part of a continuing series of "Estuary-of-the-Month" Seminars, held with the objective of bringing to public attention the important research and management issues of our Nation's estuaries. To this end, participants first presented historical and scientific overviews of the bay area, followed by an examination of management issues by scientists and resource managers involved in Tampa and Sarasota Bays.

We gratefully acknowledge the assistance of Dr. Ernest D. Estevez of the Mote Marine Laboratory, who had principal responsibility for assembling the speakers and whose familiarity with the bay area and its people was invaluable. Dr. Estevez would like to express his appreciation for the dedicated efforts of Linda Franklin, Laurie Fraser, Judy Jones, Greg Blanchard, New College Library and the County of Sarasota. The seminar was coordinated in Washington by Catherine L. Mills, EPO Regional Coordinator, with the help of other members of the EPO staff.

Questions concerning these proceedings may be directed to the NOAA Estuarine Programs Office by writing to Room 625 Universal South, 1825 Connecticut Avenue NW, Washington, D.C. 20235, or by calling (202) 673-5243.

TAMPA AND SARASOTA BAYS
ISSUES, RESOURCES, STATUS, AND MANAGEMENT

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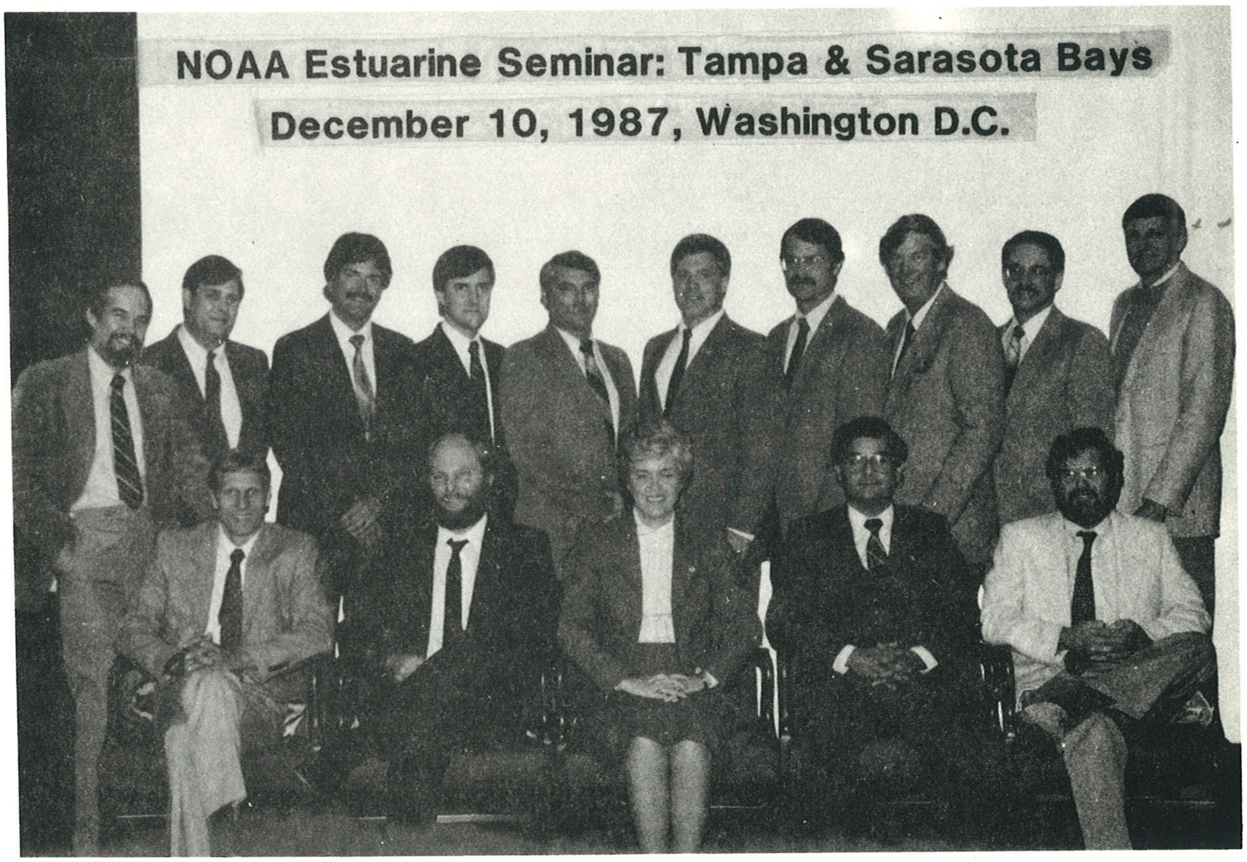

NOAA "Estuary-of-the-Month" Seminar speakers on Tampa and Sarasota Bays, December 10, 1987. Seated, from left: J.O. Roger Johansson, Kenneth D. Haddad, Julia E. Greene, Ernest D. Estevez, William J. Tiffany, III. Standing, from left: Jack Merriam, John V. Betz, Peter A. Clark, Ronald F. Giovannelli, T. Duane Phillips, Michael J. Perry, Michael S. Flannery, Roy R. "Robin" Lewis, III, Carl R. Goodwin, William Seaman.

INTRODUCTION

Reviews of existing data and literature have deservedly become regular tasks in the development of natural resource management plans. In the cases of Tampa and Sarasota Bays, literature reviews and syntheses actually preceded the establishment of management programs. The 1982 Tampa Bay Area Scientific Information Symposium --or Tampa BASIS-- led to a series of management task forces and eventually to the Agency on Bay Management, administered by the Tampa Bay Regional Planning Council. The Agency's bay plan, "The Future of Tampa Bay" drew heavily on the proceedings of Tampa BASIS. More recently, the Southwest Florida Water Management District is producing a legislatively mandated plan for Tampa Bay, the implementation of which will draw upon a data compilation program conducted for the District by the University of South Florida's Department of Marine Science. Likewise, the proceedings of a 1987 Sarasota Bay Symposium being prepared by Mote Marine Laboratory will provide important technical background for the management conference to be convened under the National Estuary Program, beginning late in 1988.

These NOAA "Estuary-of-the-Month" Symposium proceedings shall contribute to the progress of resource management in both bays. For the first time, the similarities and differences of the two bays are treated together, although it is obvious that more is left to learn concerning their relationship than is known already.

These proceedings appear at a time when two other useful literature reviews will become available, one for each bay. The U.S. Fish and Wildlife Service is publishing an Estuarine Profile on Tampa Bay which is current to approximately 1985, and forms a useful link between the Tampa BASIS proceedings and this report. Sarasota Bay information bridging the Sarasota Bay Symposium and this report appears in the Governor's nomination of the bay to the U.S. Environmental Protection Agency, for inclusion in the National Estuary Program. In fact, the paper by Estevez and Merriam contained in this report was adapted from the NEP document, with consent of the EPA.

Despite the fact that symposium speakers have worked in the same bays for years and interact at conferences, workshops, and in other arenas, all participants left the symposium with new insights to the bays, their own work, and the work of others. There was general support for periodic, technical exchanges which have not occurred as often as policy or planning meetings in recent years. The most interesting development was agreement on the value of an ecological model for the bay area, proposed by Carl Goodwin of the U.S. Geological Survey. An ecosystem model would help identify areas where new research is needed, make maximum use of existing data, and provide a mechanism to link lines of bay-related research which have been isolated along traditional, academic lines for too long. In fact, the new water management district plan for Tampa Bay provides for development of an ecosystem model during the next five years, and allocates more than one-half million dollars for that purpose.

Finally, it seems that efforts to manage coastal resources are beginning to catch up to the phenomenal growth of population which has caused so much uncontrolled, adverse environmental impact. The pace of resource management is bound to quicken even more as programs take effect in Tampa and Sarasota Bays, leading us to believe that universities, government laboratories, private research centers, and consulting firms will have to grow in size and expertise so as to respond effectively to public needs for research and planning.

Ernest D. Estevez
Kumar Mahadevan
Mote Marine Laboratory
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GEOGRAPHY AND ECONOMY OF TAMPA BAY AND SARASOTA BAY[1]

Peter A. Clark and Richard W. MacAuley
Tampa Bay Regional Planning Council
St. Petersburg, Florida

PHYSICAL GEOGRAPHY

Tampa and Sarasota Bays are located on the west central coast of peninsular Florida (Figure 1). Tampa Bay was formed as a drowned river valley during the melting of the last major ice age of the Pleistocene Epoch. During that same time period, Sarasota and Palma Sola Bays were formed as lagoons behind a chain of barrier islands.

During the Great Ice Age, the rise and fall of sea level created six terraces and historic shorelines in the Tampa Bay Region. The terraces and shorelines form belts and occur in step-like formation typically running parallel to and rising inland from the coastline.

Tampa Bay is the largest open water estuary in the state of Florida. The estuary is roughly a y-shaped system 35 miles in length and 10 miles wide. The geographic subdivisions of the bay are represented on Figure 2. Combining the open water measurements and intertidal wetland areas provides the summary of area measurements for Tampa Bay; these are reported on Table 1. In addition, shoreline length measurements for Tampa Bay are included on Table 2.

Table 1. Summary of areal measurements for subdivisions of Tampa Bay, including emergent wetlands (Lewis and Whitman 1985).

Subdivision Name	mi^2	km^2	Acres	Hectares
1. Old Tampa Bay	80.5	200.7	51,542.0	20,067.2
2. Hillsborough Bay	40.2	105.3	26,119.6	10,534.3
3. Middle Tampa Bay	119.7	309.9	76,547.1	30,990.7
4. Lower Tampa Bay	95.2	246.6	60,906.5	24,658.4
5. Boca Ciega Bay	35.9	93.1	22,985.6	9,305.9
6. Terra Ceia Bay	8.0	20.6	5,098.3	2,064.0
7. Manatee River	18.6	54.6	11,935.1	5,462.0
TOTAL:	398.1	1,030.8	256,164.9	103,082.5

[1]Presented in 1987 by Julia E. Greene, Executive Director, TBRPC.

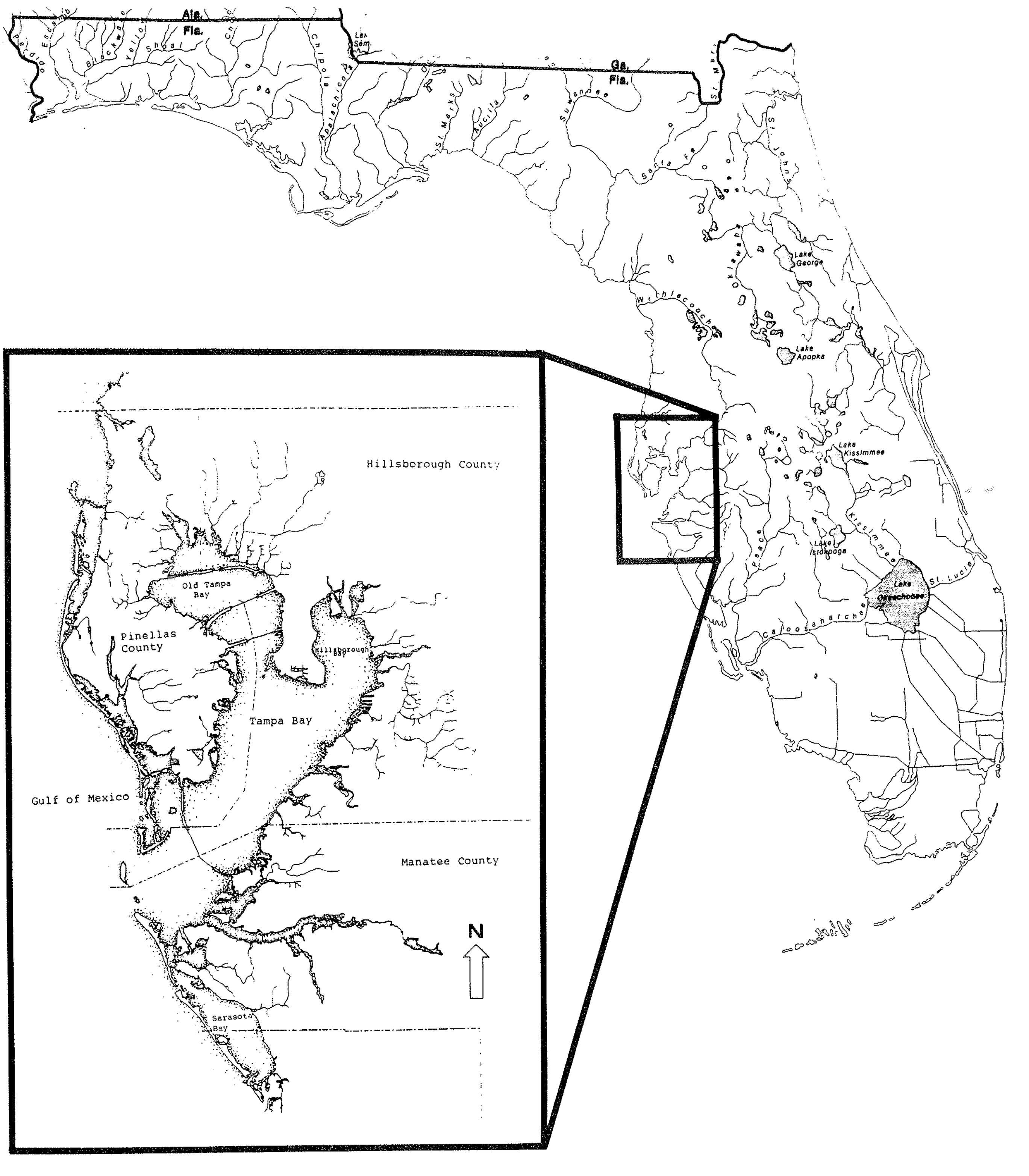

Figure 1. Location of Tampa Bay in the State of Florida.

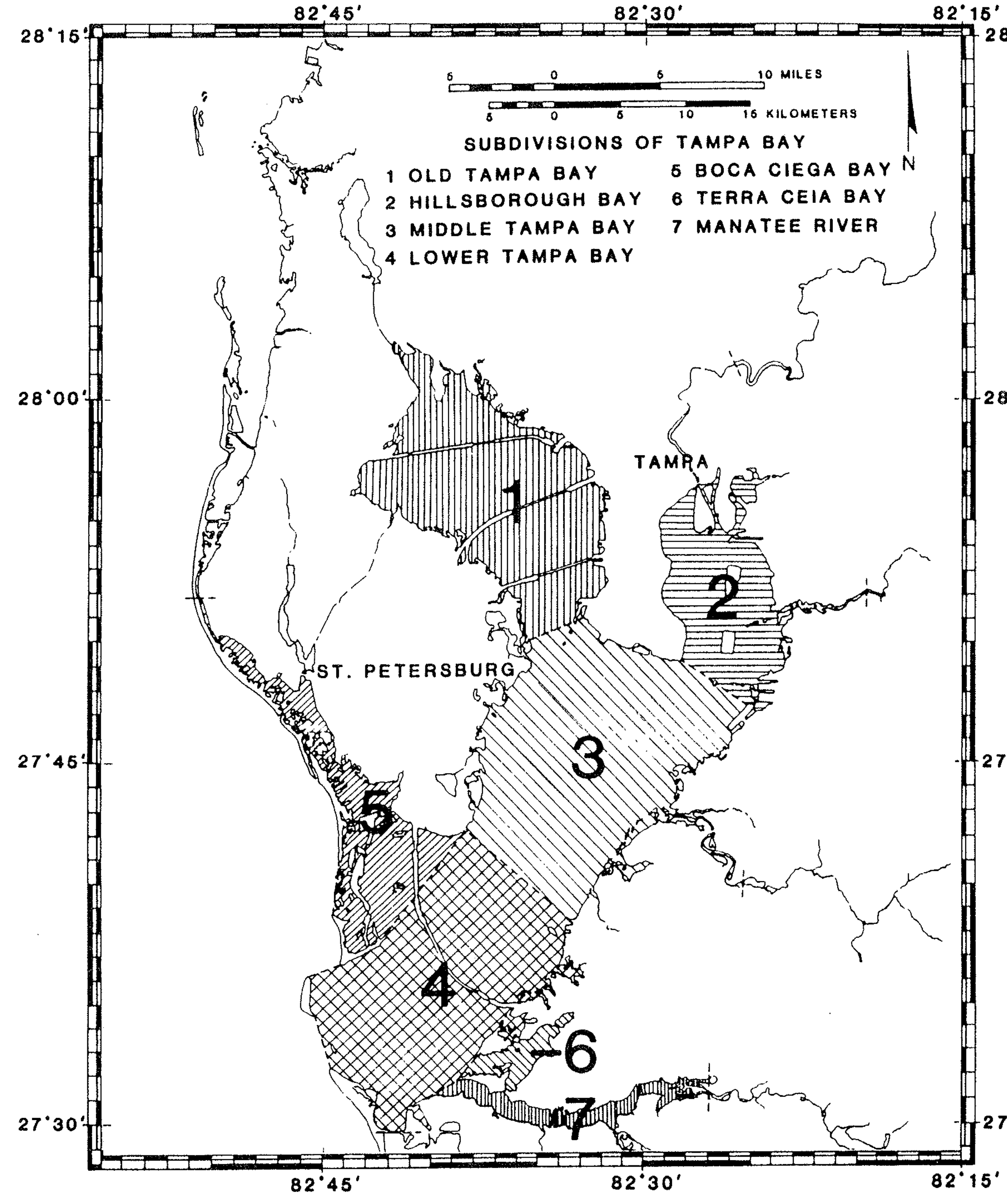

Figure 2. Subdivision of Tampa Bay (Lewis and Whitman, 1985).

Table 2. Shoreline lengths of subdivisions of Tampa Bay (Lewis and Whitman 1985).

Subdivision Name	mi	km
1. Old Tampa Bay	211.1	339.8
2. Hillsborough Bay	207.0	128.6
3. Middle Tampa Bay	163.3	262.8
4. Lower Tampa Bay	75.6	121.6
5. Boca Ciega Bay	180.5	290.4
6. Terra Ceia Bay	25.9	41.6
7. Manatee River	118.7	191.0
TOTAL:	903.7	1,454.2

Sarasota Bay is approximately 17 miles (27.4 km) long and 3 miles (4.8 km) wide and is connected to Tampa Bay on the south by Anna Maria Sound and Palma Sola Bay.

Water level fluctuations within the bay systems occur as a combination of diurnal and semidiurnal tides. The change in water level results from the sun (diurnal) promoting one high and one low tide daily, while the moon (semidiurnal) facilitates two approximately equal high and low tides per day. The combination of diurnal and semidiurnal conditions ordinarily provides a mixture of both the results in two unequal high tides and two unequal low tides each day.

The watershed, or the area in which all rainwater will eventually drain into the bay, is depicted in Figure 3 and is approximately 1,800 square miles (4,623 km) in size (Lewis and Estevez 1988). Approximately 85 percent of all freshwater flow to the bay consists of the discharges of the four rivers (Lewis and Estevez 1988) which include the Hillsborough, Alafia, Little Manatee, and the Manatee. Both Tampa Bay and Sarasota Bay additionally receive surface water inputs from numerous smaller tidal creeks.

All of these estuarine water bodies have had past physical modifications created to:

- Develop and expand port facilities
- Improve navigation
- Provide transportation routes across the water
- Build waterfront homes
- Construct power plants
- Develop recreational areas
- Provide flood control

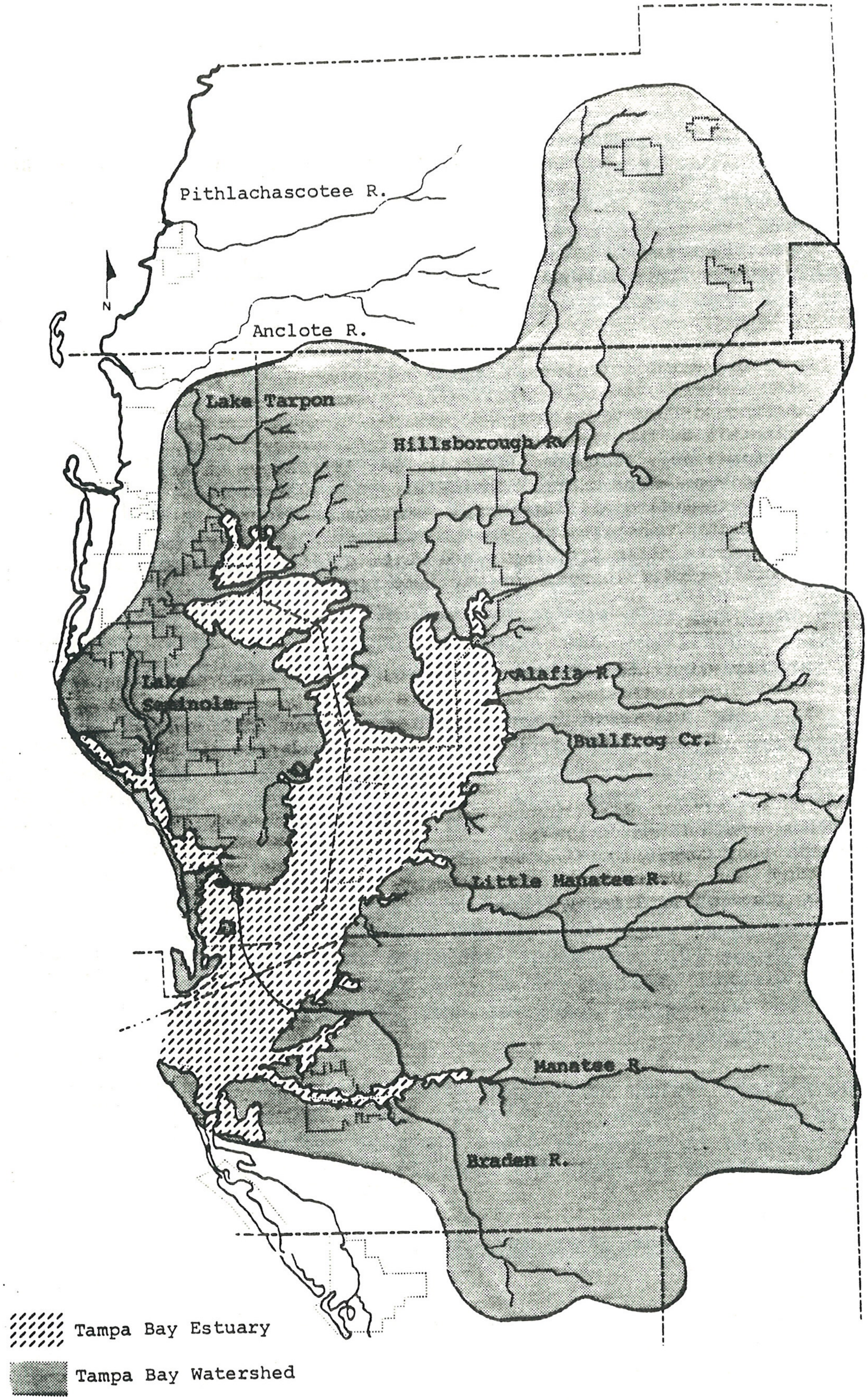

Figure 3. The Tampa Bay watershed (TBRPC, 1984).

The Tampa Bay estuarine system is criss-crossed and modified by four major causeways and an extensive network of dredged canals. Creation of the 35 mile shipping channel resulted in 70 million cubic yards of bay bottom being moved and deposited as large spoil island or submerged disposal areas in the bay (Figure 4). Previous to dredge and fill activities the average depth in Tampa Bay was 11 feet. Due to the extent of bay development, the average depth has increased by one foot bay-wide and the surface area has diminished by 3.6 percent (Goodwin 1987).

CLIMATE

The Tampa Bay Region has a subtropical climate that is characterized by long, warm, humid summers and warm winters. In general terms, the mild subtropical climate of the watershed is a reflection of the low-geographical relief, proximity to the Gulf of Mexico and the Atlantic Ocean and the watershed's relatively low latitude (Schomer, Drew and Johnson in press). The slight relief allows an uninterrupted movement of wind and rain across the terrain. Because of its history of mild climatic conditions and abundant sunshine, the area surrounding Tampa and Sarasota Bays has become known as the "Florida Suncoast".

The average bay area temperature is 23°C (73°F), and freezing temperatures are experienced only four nights each year on the average. Total rainfall averages 53 inches (134.6 cm) per year. More than half the rainfall occurs from June through September, primarily from thunderstorms. Approximately 60 to 100 thunderstorms occur in an average year, over 85 to 90 days (Lewis and Estevez 1988).

South Florida has experienced more hurricanes and tropical storms than any other equal sized area of the United States. From Cedar Key to Fort Myers, eleven (11) storms of hurricane intensity have passed inland in recorded history (Schomer et al. in press). The bay area is most often hit in the latter part of the hurricane season, usually in September and October.

The primary forces associated with the passage of a hurricane are wind, storm surge and rain. In Florida, about 75% of all damage related to tropical storms is caused by tidal flooding, with the remaining 25% of the damage attributed to winds and rainfall (Schomer et al. in press).

POPULATION AND SOCIAL FEATURES

Tampa Bay is bordered by the counties of Pinellas, Hillsborough and Manatee, while Sarasota Bay is bordered by Manatee and Sarasota Counties. In addition, the two estuaries share twenty-two local governments along their peripheries (Figure 5); two regional planning councils (Tampa Bay and Southwest Florida); and one water management district (Southwest Florida). Population estimates from 1890 reveal that

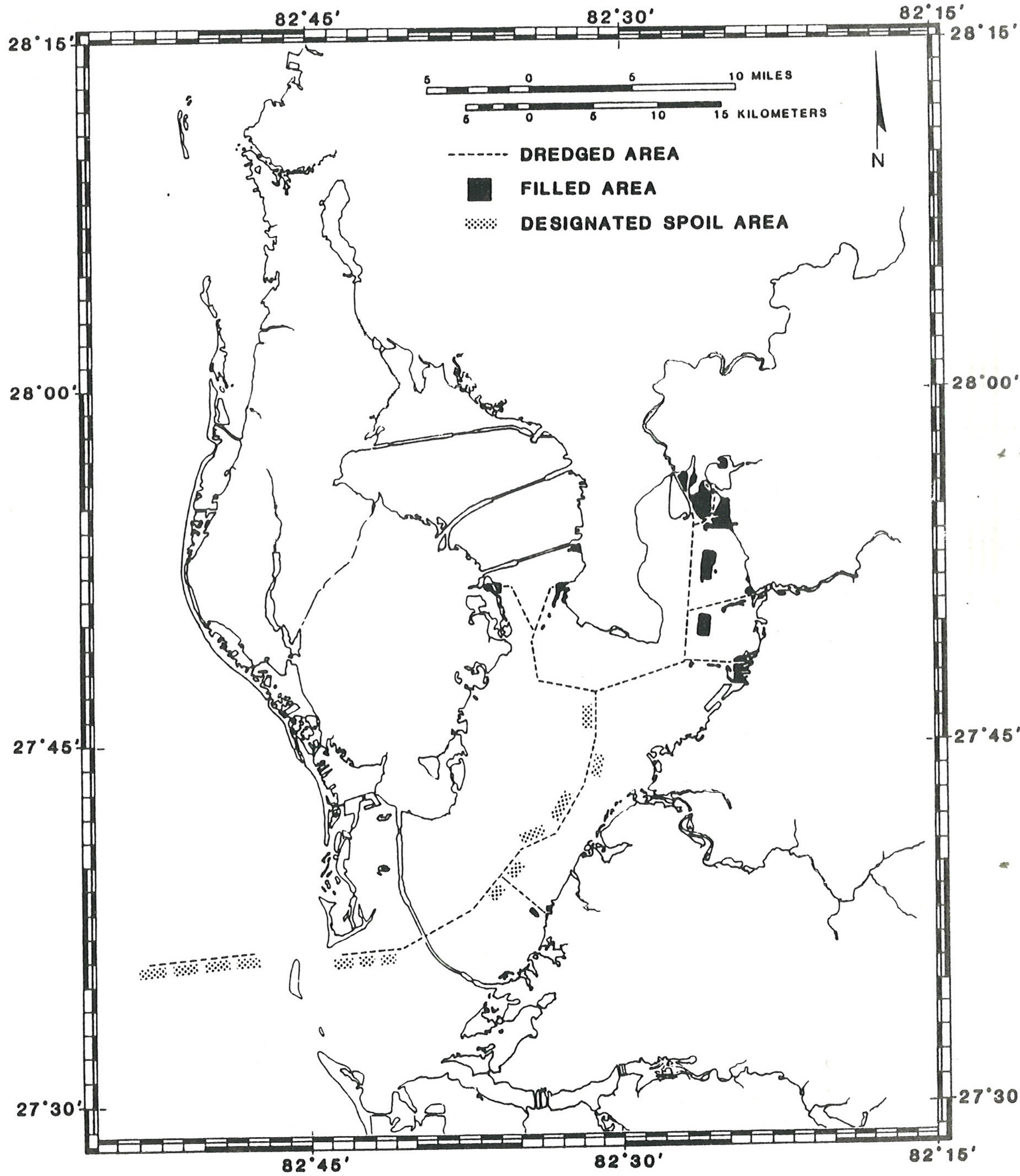

Figure 4. Areas of Tampa Bay dredged or filled in the past 100 years for port development (Fehring, 1985).

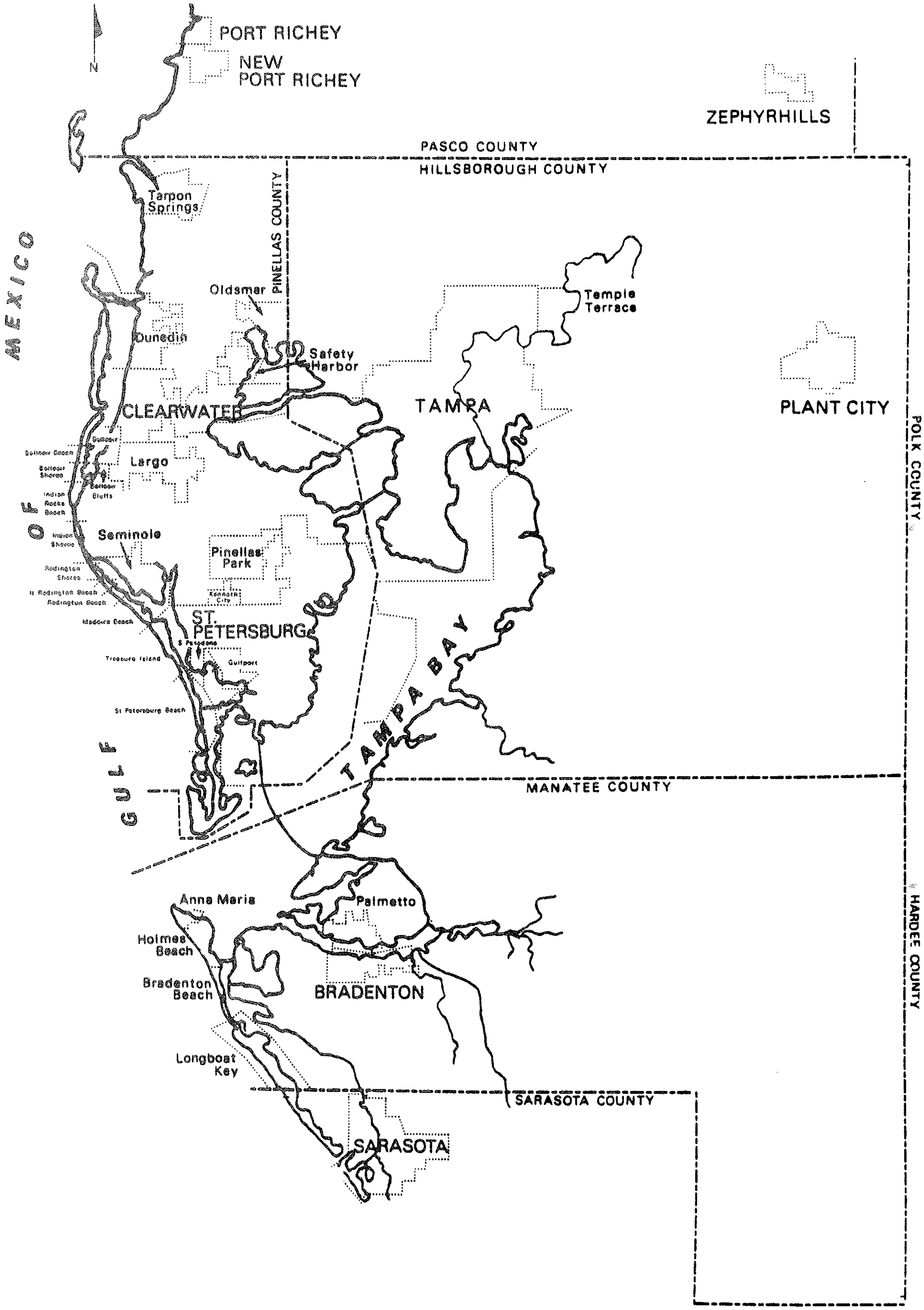

Figure 5. Political boundaries within the Tampa Bay Region (TBRPC, 1984).

approximately 17,836 residents inhabited Hillsborough County (including what is now Pinellas County) and Manatee County (including what is now Sarasota County) (Figure 6). This number increased approximately 500 percent to 87,923 in 1910 (U.S. Department of Commerce 1913). The estimated population of the four counties in 1950 was approximately 473,000, increasing 260 percent to approximately 1.23 million residents in 1970 (Bureau of Economic and Business Research 1988). The 1987 estimated population of the area was approximately 2.06 million residents. Medium projections indicate that the area's population will reach 2.53 million by the year 2000 --an 18.5% increase over the 1987 figure (BEBR 1988).

The Tampa Bay region supports its own symphony orchestra, dance and drama companies, and public and private art galleries. In addition, the region contains many major attractions which include:

- Busch Gardens
- Clearwater Marine Science Center
- Museum of Science and Industry
- Ringling Museum Complex
- Ruth Eckerd Hall
- Salvador Dali Museum
- Sunken Gardens, and
- Tampa Bay Performing Arts Center.

Professional sports in the area include the Tampa Bay Buccaneers (football) and the Rowdies (soccer). The Tampa Bay region served as host for the Super Bowl in 1984 and will again host Super Bowl XXV in 1991.

There are numerous educational and research facilities located in the Tampa Bay and Sarasota Bay areas. The University of South Florida maintains three campuses in the four county area -- Tampa (main campus); St. Petersburg (Bayboro); and Sarasota (New College). The Bayboro area of St. Petersburg is also the site of the Florida Department of Natural Resources' Bureau of Marine Research, and the Florida Institute of Oceanography. The federal Department of Interior, U.S. Geological Survey (USGS) maintains a field office in Tampa, and another office is being proposed for the Bayboro area of St. Petersburg. Finally, extensive research and study are undertaken at the Mote Marine Laboratory, located in Sarasota.

ECONOMICS

The presence of Tampa and Sarasota Bays on the Florida "Suncoast" has historically shaped and continues to influence the economic base of the counties and cities surrounding them. Together, the bays provide two of the finest natural harbors on the Gulf coast of peninsular Florida. Fishing villages along the shores of both bays became active trade centers in the early 1800's, stimulated by thriving agriculture and cattle industries (Powell 1973). The expansion of the railroad system

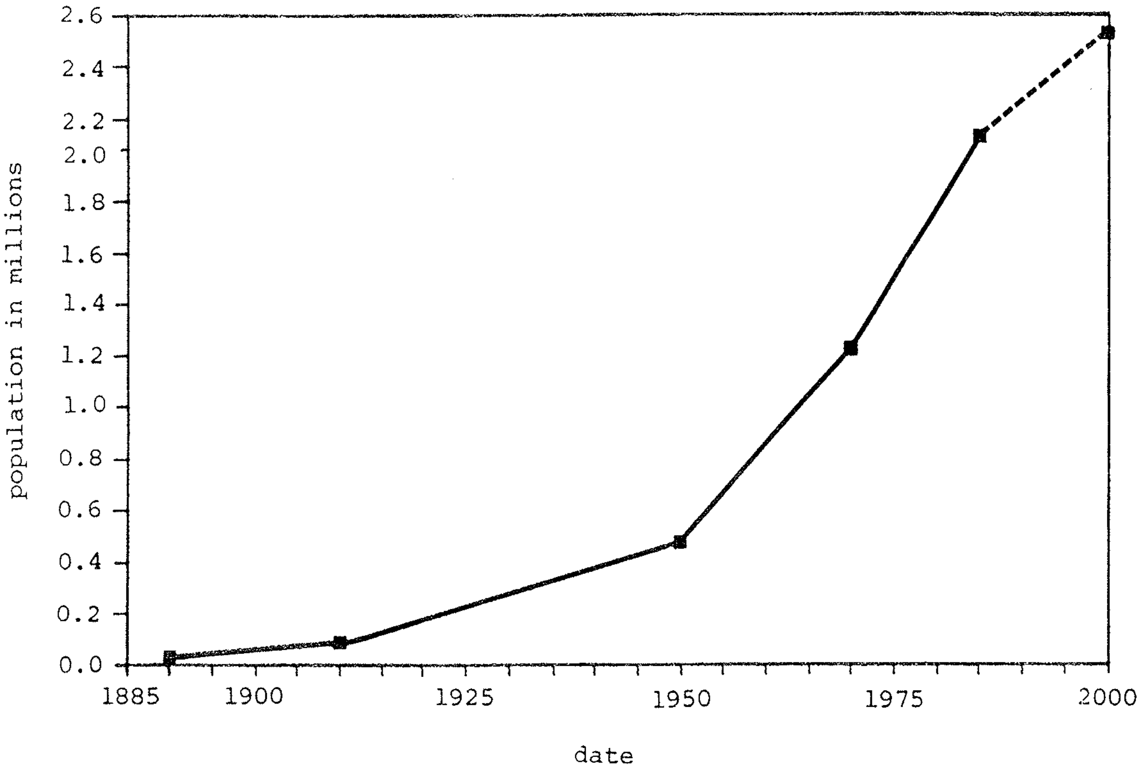

Figure 6. Recorded and projected population estimates for Hillsborough, Pinellas, Manatee and Sarasota Counties (Department of Commerce, 1913; BEBR, 1988).

toward the end of the 19th century is perhaps the single, most important reason why the city of Tampa transformed from a viable port city to a productive metropolis; moreover, the city's development into a major seaport and trading center influenced the growth and development of the entire west coast of Florida (Mormino and Pizo 1983).

Many of the bay-influenced industries historically important to the Tampa and Sarasota Bays area remain key components of the local economy today. An economic base analysis conducted in 1986 identified agriculture, boat building, commercial fishing, construction and port activities to be export industries, or those industries which "drive the local economy" (TBRPC 1986). There is much evidence that tourism played a major role in the local economy during the 1800's (Pumphrey 1987). Since the 1950's, however, the bays have increased in economic importance for a variety of reasons, principal among these being benefits accrued by the sanitary and electric service industries, residential waterfront property owners, and the recreation service industry.

Commercial fishing and port or shipping activities are perhaps the most noticeable industrial uses of the two estuaries. Although commercial fishermen are reporting that both finfish and shellfish have become less abundant over the past 20 years, the industry remains important to the local economy. In 1984, approximately 2,000 commercial fishermen plied their trade in Hillsborough, Manatee, and Pinellas Counties, landing a total of 22.1 million pounds of finfish and shellfish, with an ex-vessel value of approximately $19.3 million (TBRPC 1986). Port Tampa and Port Manatee, both located on Tampa Bay, are major sources of employment and income for bay area residents. In addition, it has been estimated that shippers and consignees that engage in commerce on Tampa Bay realize an annual savings in transportation related costs of approximately $281 million, i.e., waterborne commerce versus railroad or truck commerce (TBRPC 1986).

Tampa and Sarasota Bays continue to serve as receiving water bodies for discharges of treated wastewater from municipal sewage treatment plants. This use of the bays provides a cost savings of approximately $238 million, when taking into consideration the alternative of secondary wastewater treatment and spray irrigation (TBRPC 1986). In addition, Tampa Bay serves as a source for condenser cooling water and a disposal site for waste heat water from five steam electric power plants operated by the Florida Power Corporation and the Tampa Electric Company (Phillips, Mahadevan and Garrity this report). This results in a cost savings of between $40 and $126 million when considering the alternatives of constructing a closed-cycle cooling system and on-site cooling towers (TBRPC 1986).

The construction industry continues to be influenced by the presence of both bays, as evidenced by the competition to build residential subdivisions, condominiums, office buildings and restaurants on the limited amount of land which offers a water vista. The value of residential waterfront property along Sarasota Bay has been estimated at $1.9 billion (Daltry 1988). Although a similar estimate for Tampa Bay is not available, a 1986 study (TBRPC) determined that the most valuable attribute (or benefit) provided by Tampa Bay to owners of single-family waterfront property was the water view.

Tourism and recreation are major industries along the Florida Suncoast, generating millions of dollars each year. Tampa Bay and Sarasota Bay are two of the primary attractors of tourists, as well as permanent residents, for recreation. One useful indicator of tourism and recreational activity is employment, particularly in those industries which are sensitive to tourist expenditures. The retail trade and services industries, or sectors, are especially influenced by tourism, specifically the hotel/motel industry, eating and drinking establishments, and recreation services. The economic base study, referred to previously, identified these three sectors as being export industries and, therefore, key components of the local economy (TBRPC 1986). Although the economic study focused on tourism related employment in Hillsborough, Manatee, and Pinellas Counties only, it is believed that the findings reflect the economic base of Sarasota County, as well.

Another indicator of tourist activity is that of revenues generated by a tourist development (or resort) tax, presently levied by Hillsborough, Manatee, and Pinellas Counties on hotels, motels, and condominiums rented or leased for a term of six months or less. In 1987, 26 of Florida's 67 counties levied a resort tax. Hillsborough, Manatee, and Pinellas Counties accounted for approximately 13.2% ($9,248,073) of the state total of $69,983,047 (Department of Revenue 1988).

When compared with Florida's eastern seaboard and other Gulf coast states, the Florida Suncoast ranks as one of the leading sites of marine recreational activity, exceeding 25 million activity occasions per year in 1980 (Department of Natural Resources 1981). Recreational fishing, sailing, swimming, and beach activities are some of the recreation-related benefits provided by both the Tampa Bay and Sarasota Bay systems. Although tourist and recreational benefits are difficult to quantify, there have been attempts made to identify the potential magnitude of the recreational benefits associated with Tampa Bay and Sarasota Bay. A 1986 economic impact statement addressing the designation of Sarasota Bay as an Outstanding Florida Water (OFW) estimated the total annual economic value of recreational fishing in the Sarasota Bay area to be $38,001,471 (in 1983 dollars) (Dept. of Environmental Regulation 1986). The economic value of other types of water-related recreation, including saltwater boat ramp use and beach activities, was estimated to be $9,949,223, for a total of $47,950,694 (in 1983 dollars). The same methodology was used in another study published in 1986, which estimated the total annual economic value of recreational fishing and other types of water-related recreation for Hillsborough, Manatee, and Pinellas Counties to be $220,176,156 (again, in 1983 dollars) (TBRPC 1986).

There are over 200 public and private marinas located on the periphery of Tampa Bay and Sarasota Bay, some of which are included in Figure 7. The number of recreational (pleasure) boats registered in Hillsborough, Manatee, Pinellas; and Sarasota Counties is also indicative

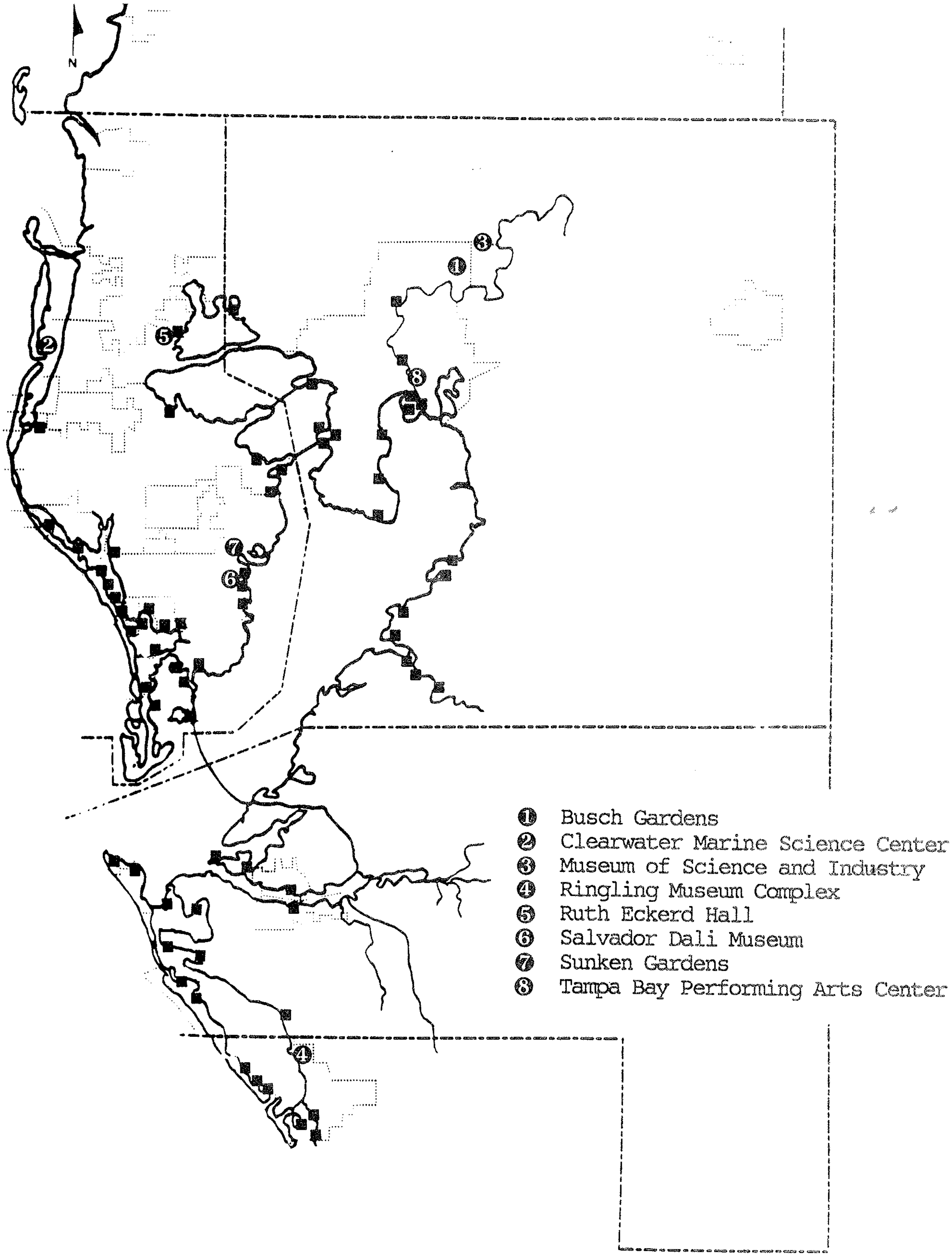

Figure 7. **Selected marinas and tourism centers located along Tampa Bay and Sarasota Bay.**

of water-related recreational demands. In 1984, the retail sales reported for pleasure boats in the Tampa Bay region was approximately $184 million (TBRPC 1986). Table 3 illustrates the number of pleasure boats registered in FY 1984-85. The four counties accounted for approximately 17 percent of the total number of pleasure boats registered in Florida.

Table 3. Pleasure boats registered FY 1984-85 (BEBR 1986).

Hillsborough	33,447
Manatee	11,657
Pinellas	34,541
Sarasota	14,702
TOTAL:	94,347
Florida:	554,675

The Tampa Bay and Sarasota Bay estuarine systems are both directly and indirectly vitally important economic assets to the Florida Suncoast. When taking into consideration the myriad of uses and attributes of both bay systems including commercial fishing, shipping, and port-related activities, benefits to the sanitary and electric service industries, waterfront property values, and tourism and recreation, their total annual value can be placed at approximately $3 billion (Table 4). Strong evidence supports both Tampa and Sarasota Bays' significant contribution to the Florida Suncoast's rapid growth and development over the past 100 years. With active protection and management, both bays will continue to serve as a valuable, natural --as well as economic-- resource.

Table 4. Direct and indirect economic benefits of Tampa Bay and Sarasota Bay (millions of dollars) (TBRPC 1986; Daltry 1988).

Bay Use	Benefit
Commercial fishing[1]	$ 19.3
Waterborne commerce[1]	281.0
Sanitary services[2]	219.3
Electric services[3]	63.3
Waterfront property[4]	1,900.0
Tourism/recreation[5]	461.4
TOTAL:	$2,944.3

[1]Tampa Bay only.

[2]Considers the alternatives of secondary treatment and spray irrigation.

[3]Considers the alternatives of a closed-cycle cooling system and "helper" cooling towers.

[4]For Manatee and Sarasota Counties located on Sarasota Bay only.

[5]Includes economic value of water-related recreational activities and tourist development tax revenues.

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TAMPA AND SARASOTA BAYS: WATERSHEDS AND TRIBUTARIES

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INTRODUCTION

Unlike many estuaries in the United States, neither Tampa nor Sarasota Bay is associated with a large river. All tributaries flowing to these bays originate on the Florida peninsula and, consequently, are relatively small (Figure 1). For instance, the largest river flowing to Tampa Bay, the Hillsborough, is only 55 miles long. Despite their limited size, tributaries to Tampa Bay are important influences on that bay's physico-chemical characteristics. For Sarasota Bay, where tributaries are more reduced, these relationships are less pronounced. For both bays, however, freshwater tributaries and their associated brackish zones are important to estuarine structure and perform ecological functions integral to bay productivity. Accordingly, resource managers and public officials in the region have clearly stated that the proper management of these tributaries is essential for developing bay management plans.

In this paper, the status of tributaries to Tampa and Sarasota Bays is reviewed. Emphasis is placed on water quality and seasonal quantities of flow and how these characteristics are related to land use and other human impacts in the watersheds. A brief synopsis of regional meteorological conditions affecting runoff is also presented. Certain information presented in this chapter was synthesized from other reviews concerning Tampa Bay, particularly those by Lewis and Estevez (1988) and Drew, Schomer, and Wolfe (in review). For the sake of brevity, references are not extensively used here and uncited information is either original or contained in one of the above reviews. Many data presented here are only estimates, which the reader should consider for future use.

METEOROLOGICAL CONDITIONS

The delivery of fresh water to Tampa and Sarasota bays from their respective watersheds is a product of the meteorological conditions in west-central Florida. The distribution of rainfall is the most important variable, but the seasonal variation of other factors such as solar insolation, temperature, and evapotranspiration also affect runoff to the bays.

West-central Florida experiences a subtropical climate with mild winters and long humid summers. The mean annual temperature for the Tampa Bay area is 22.3^{o}C (Wooten 1985) with slightly warmer conditions

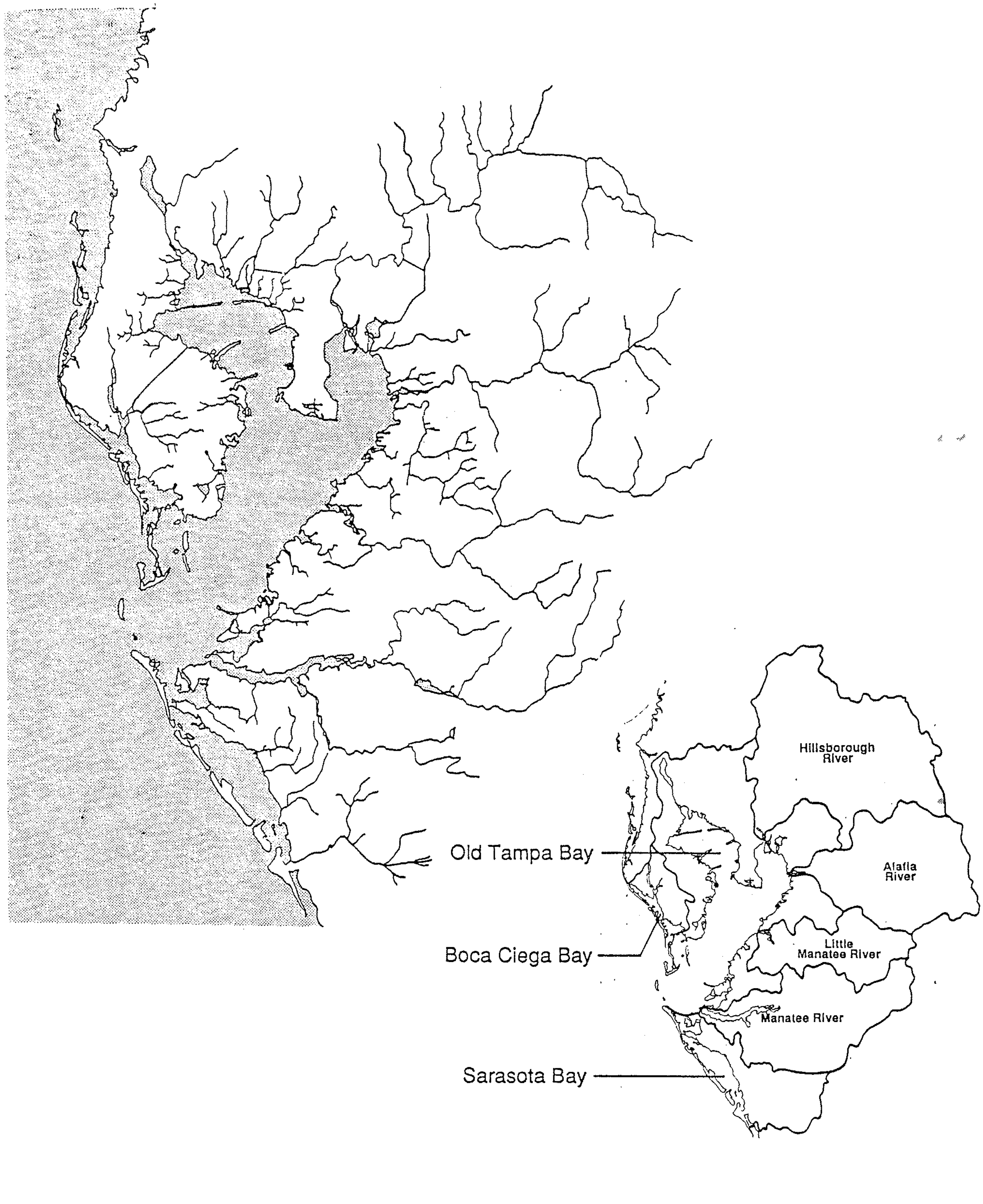

Figure 1. Location of tributaries to Tampa and Sarasota Bays and major drainage areas.

occurring near Sarasota Bay to the south. Average monthly temperatures range from 16.0°C to 27.8°C for January and August, respectively. Mean annual precipitation for the Tampa Bay watershed is approximately 54 inches (Heath and Conover 1981). Based on data from 1941 to 1970, Palmer (1978) determined that yearly rainfall increased concentrically away from Tampa with the most rain falling in the eastern portions of Hillsborough and Manatee Counties (Figure 2). For the period 1978 to 1985, however, Stowers and Tabb (1987) reported a shift from this historical pattern with rainfall increasing in Pinellas and northwestern Hillsborough Counties and decreasing in the eastern portions of the watershed. The authors attributed this to a change in meteorological conditions resulting in a shift in summer winds from easterly to southwesterly but state that it is not known whether this represents a short-term cycle or a long-term displacement. What is clearly known is that the Tampa and Sarasota Bay area has recently been experiencing dry conditions, as rainfall has been below average most years since 1961. Palmer and Bone (1977) indicated that rainfall at 10 of 14 sites in west-central Florida during 1961 to 1976 was the lowest of any of 16 year period since 1915. More recently, major droughts occurred in west-central Florida during 1981 and 1985.

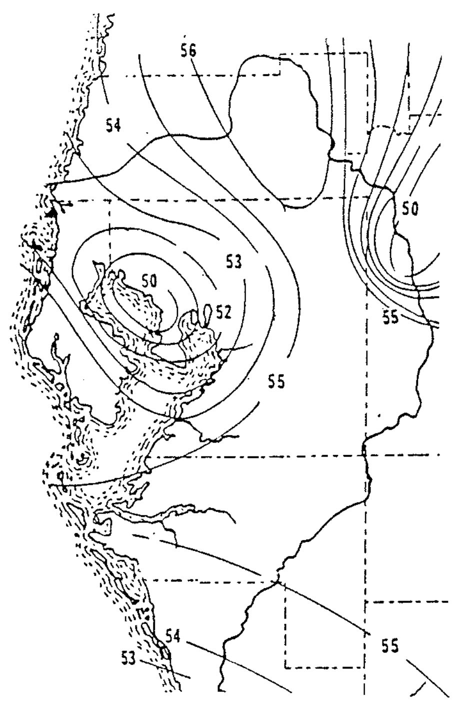

Figure 2. Distribution of average annual rainfall (inches) in the Tampa Bay region of west-central Florida, 1941-1970 (after Palmer 1978).

Apart from long term trends in yearly precipitation, the most important characteristic of rainfall in the region is its pronounced seasonal distribution. A distinct wet season occurs from June through September during which approximately 60% of the total yearly precipitation falls (Figure 3). This summer wet season is the result of local sea-breeze/convection circulation patterns in which moist air from the Gulf moves inshore with daytime sea breezes and converges with convective air currents caused by the rapid heating of the land surface. Rainfall produced from this process generally occurs as brief thunderstorms (1-2 hrs) accompanied by strong winds. These thunderstorms occur most often during late afternoon or early evening hours, the period of maximum atmospheric convergence. One characteristic of these summer thunderstorms is the high spatial variation in rainfall. Due to the location and variable moisture content of different storm clouds, rainfall can vary markedly between stations of close proximity, and monthly variations of more than 5 inches have occurred in areas situated only a few kilometers apart.

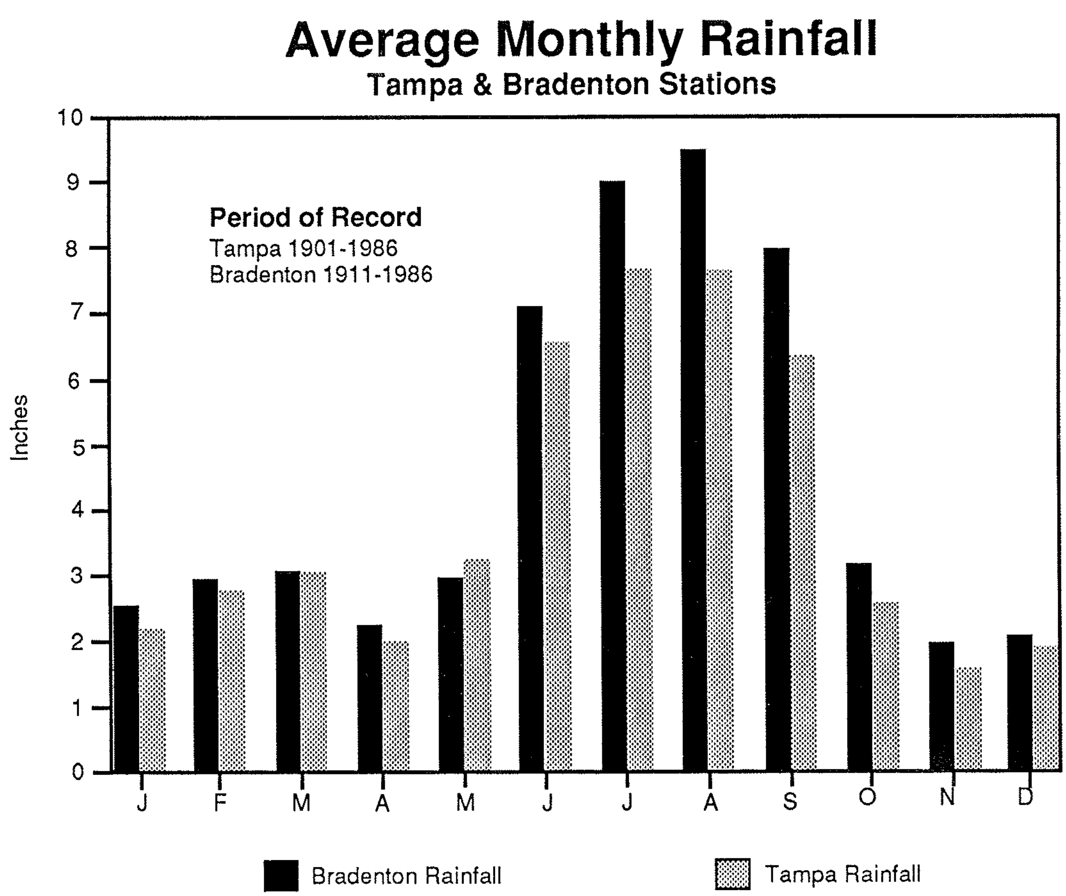

Figure 3. Average monthly rainfall for the Tampa and Bradenton stations.

Rainfall during the wet season is sometimes supplemented by the passage of tropical cyclones (tropical storms and hurricanes), which most commonly occur from August through October. During the period 1932-1982, five tropical storms and eight hurricanes passed within 75 kilometers of Tampa Bay (Wooten 1982). Gentry (1974) reported that 5-10 inches of rain are usually recorded at any one point during the passage of a tropical storm.

During November through May rainfall is considerably less than in the summer wet season. In contrast to the summer's convective thunderstorms, rainfall during this five to six month dry season is associated with the passage of large frontal air masses over the state. Generally, winter cold fronts proceed in a southerly to southeasterly direction and create a preceding band of rainfall which extends along a northeast-southwest axis. Rainfall events associated with the passage of frontal systems are generally of longer duration but much less intensity than summer thunderstorms. These cold front rains are most common during January to March, creating a brief elevation in dry season rainfall. The driest periods of the year are normally November and April or May, as these months occur between periods of intense convective and frontal activity.

Solar radiation varies little geographically, with a daily average value of 444 langleys. Highest values occur in spring rather than near the summer solstice due to increased cloud cover and precipitation (Figure 4). Correspondingly, relative humidity is normally lowest in the spring. Evapotranspiration varies spatially throughout west central Florida; estimates vary from 30 to 48 inches per year. Based on pan evaporation data, average yearly evaporation from open water bodies in the region is between 48 and 52 inches, which is only slightly less than the average annual rainfall. Pan evaporation rates are highest in the spring (Figure 4).

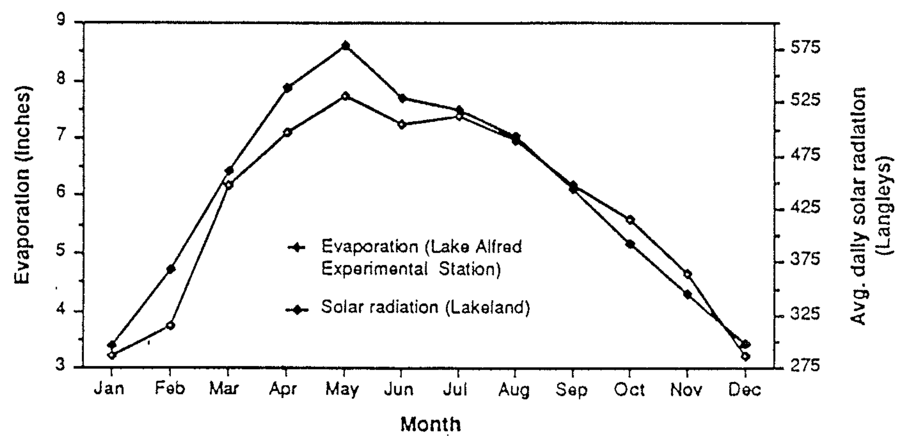

Figure 4. Average monthly ventilated pan evaporation and solar radiation in the eastern Tampa Bay watershed (reprinted from Drew et al. in review).

SEASONAL STREAMFLOW CHARACTERISTICS

The yearly cycle of freshwater inflow to the bays closely reflects the seasonal progression of climatological conditions in the region. Average monthly streamflow values for three long term stations on rivers flowing to Tampa Bay are illustrated in Figure 5. Streamflow, like rainfall, is highest in the late summer with a much smaller peak in February and March. Also, pronounced low flow periods occur in April-May and November-December. The differences between spring and wet season streamflow values, however, are generally greater than differences between spring and wet season rainfall. This is partly because streamflow is related to preceding conditions; i.e., increases in streamflow during September are associated with already high levels from August. Some of the differences between spring and late summer streamflow levels, however, are due to higher net runoff during the late summer caused by saturated soil conditions.

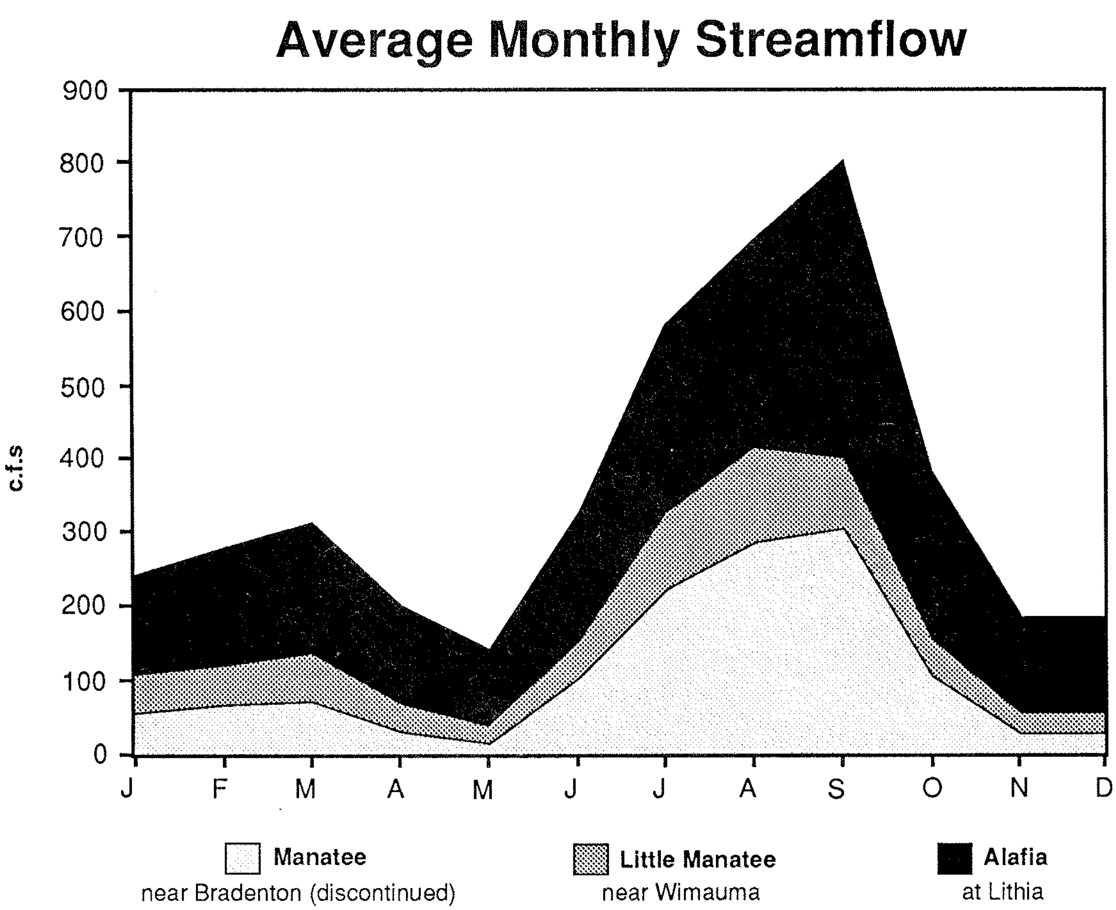

Figure 5. Average monthly streamflow for three stations on the Manatee, Little Manatee and Alafia Rivers.

Although the trend shown in Figure 5 is typical of the region, seasonal flow characteristics of streams in the area vary due to differences in factors such as basin size, land cover, depressional storage, and groundwater relationships. For instance, artesian springs flow into the Hillsborough and Alafia Rivers providing an important source of baseflow during the dry season. Of particular importance are the many minor tributaries which drain small, very flat basins. Baseflow levels in these tributaries are very small, and total yearly flows are dominated by brief periods of runoff after storm events. For these small tributaries, the relative differences between dry and wet season flows are probably greater than the values for the three rivers displayed in Figure 5.

DRAINAGE AREAS

The lands supplying runoff to Tampa and Sarasota Bays can be conceptually divided into ten drainage areas (Figure 1). Four of these areas are the respective basins of the area's major rivers,which are from north to south; the Hillsborough, Alafia, Little Manatee and Manatee Rivers. These rivers originate from the higher terraces in the eastern portion of the Tampa Bay watershed and flow in a westerly or southwesterly direction emptying into the bay on its eastern shore. The hydrology and water quality of these four rivers is addressed later in this paper.

The remaining six drainage areas are not true hydrologic basins but rather are low-lying coastal areas which are drained by small streams, canals, stormwater conduits and tidal creeks. Three of these coastal areas comprise the entire drainage to Sarasota, Boca Ciega, and Old Tampa Bays. The remaining three areas drain to the eastern shore of Tampa Bay between the mouths of the four major rivers (Figure 1).

MINOR TRIBUTARIES

The Tampa Bay Regional Planning Council (TBRPC) recently completed an ecological assessment and classification of the minor tributaries to Tampa Bay (TBRPC 1986). Forty four creeks were identified, although three of these were upstream forks of previously mentioned creeks and one was a man made canal (Figure 6). These tributaries to the bay ranged in total length from 0.5 to 17.5 miles. Although they are largely ungauged, it was assumed that average flow in most of these creeks was less than their respective tidal prism. In a review of the meteorology and hydrology of Sarasota Bay, Walton and Gibney (1988) identified six tributaries supplying runoff to Sarasota Bay. The largest of these, Phillippi Creek, drains 58 square miles and actually empties into the Bay near Little Sarasota Bay, just to the south. The remaining tributaries to Sarasota Bay are small, the largest draining only 12.7 square miles.

	CREEK	CONDITION
1.	Curlew Creek	Stressed
2.	Jerry Branch	Stressed
3.	Stevenson Creek	Stressed
4.	McKay Creek	Stressed
5.	Church Creek	Stressed
6.	Joe's Creek	Stressed
7.	St. Joe's Creek	Stressed
8.	Bear Creek	Stressed
9.	Salt Creek	Stressed
10.	Booker Creek	Stressed
11.	Tinney Creek	Stressed
12.	Grassy Creek	Natural
13.	Long Branch Creek	Restorable
14.	Allen Creek	Stressed
15.	Alligator Creek	Stressed
16.	Mullet Creek	Restorable
17.	Bishop Creek	Natural
18.	Moccasin Creek	Natural
19.	Double Branch Creek	Natural
20.	Channel A	Man-made
21.	Rocky Creek	Stressed
22.	Brushy Creek	Non-tidal
23.	Dick Creek	Restorable
24.	Woods Creek	Stressed
25.	Peppermound Creek	Restorable
26.	Sweetwater Creek	Stressed
27.	Fish Creek	Restorable
28.	Coon Hammock Creek	Restorable
29.	Broad Creek	Restorable
30.	Delany Creek	Stressed
31.	Archie Creek	Restorable
32.	Bullfrog Creek	Restorable
33.	Little Bullfrog Creek	Non-tidal
34.	Newman Branch	Stressed
35.	Wolf Branch	Restorable
36.	Cockroach Creek	Natural
37.	Piney Point Creek	Natural
38.	Little Redfish Creek	Restorable
39.	Frog Creek	Natural
40.	Cabbage Slough	Non-tidal
41.	McMullen Creek	Natural
42.	Wares Creek	Stressed
43.	Palma Sola Creek	Natural
44.	Bowles Creek	Stressed

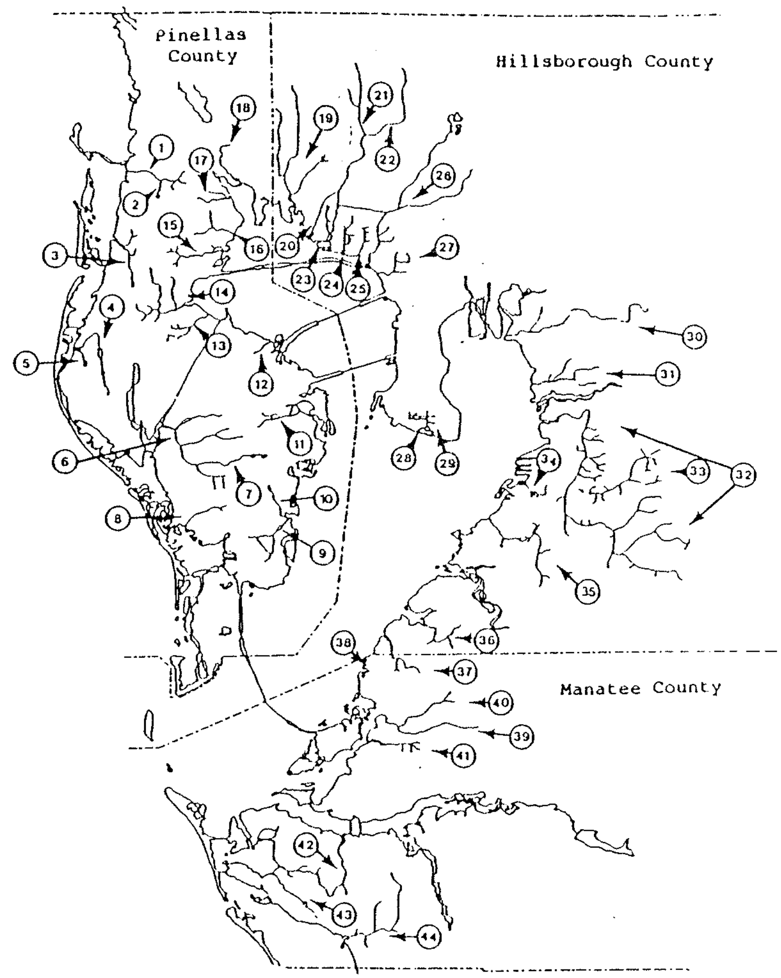

Figure 6. Location of minor tributaries in the Tampa Bay region assessed by the Tampa Bay Regional Planning Council and their ecological classification (adapted from TBRPC 1986).

Despite their small size and limited rates of flow, small tributaries and tidal creeks are extremely important components of Tampa and Sarasota Bays. Collectively, they provide hundreds of miles of low salinity habitat which is utilized as nursery areas by a wide variety of marine fishes and some important invertebrates. Many of the most valued sport and commercially harvested species in the region such as snook, red drum, pink shrimp and tarpon utilize tidal creeks during their life cycles. Some regional fishery biologists have expressed concern that the abundance and ecological condition of tidal creeks may be a dominant factor controlling the productivity of the fishery in Tampa Bay.

The TBRPC (1986) determined a subjective ecological condition for each of Tampa Bay's minor tributaries based upon a review of adjacent land use, habitat, and water quality. These creeks were then given a classification of either natural, restorable, or stressed. Of the forty tidal creeks considered, nine were classified as natural, eleven as restorable, and twenty as stressed. Among the major perturbations to tidal creeks in the area were:

- Habitat loss and water quality impacts associated with filling of adjacent wetlands;
- Loss of natural stream alignment and morphometry due to channelization and sea walling;
- Non point source pollutant loadings from urban and agricultural runoff;
- Point source pollutant loading from municipal and industrial discharges;
- Alteration of flow regimes due to stormwater runoff, channel rerouting, and impoundment.

In response to the need to better manage tidal creek resources on Tampa Bay, the TBRPC recommended several policies and guidelines to be used in developing management or restoration plans for the bay's tidal creeks. Although not listed here, these recommendations pertained to stormwater runoff management, waste effluent control and recycling, physical and habitat restoration, freshwater inflow protection, water quality monitoring, and resource-compatible land use planning.

MAJOR RIVERS

The four major rivers flowing to Tampa Bay collectively drain about 75 percent of the Bays's entire watershed. The drainage basins for these rivers range in size from 650 square miles for the northernmost Hillsborough River to 221 square miles for the Little Manatee River. Progressing from north to south, their tidal floodplains become wider and they are tidally affected further upstream. Tidal action is present at river mile 11 (mouth=0) in the Hillsborough where the river is dammed and at mile 10 in the Alafia River, whereas the Little Manatee is tidal at mile 15 and the Manatee is tidal at least to mile 19. The northern rivers (Hillsborough, Alafia) are more urbanized than the southern ones, which still contain 90% of their watersheds in wetlands, forest, range, and farmland. The Little Manatee watershed is the least urbanized of the four rivers and it is generally considered to be the river in the best ecological condition.

Average streamflow rates for these four rivers are presented in Figure 7, along with flows for four gauged minor tributaries. Average streamflow for the four major rivers correspond to their respective drainage basin areas with the Hillsborough having the greatest flow followed by the Alafia, Manatee, and the Little Manatee Rivers. Lewis and Estevez (1988) estimated that these four rivers contribute approximately 85 percent of the total flow to the bay, while Hutchinson (1983) indicated this value was near 78 percent. The two largest rivers, the Hillsborough and the Alafia, empty into Hillsborough Bay, the northeastern division of Tampa Bay. It has been estimated that Hillsborough Bay receives 63 to 77 percent of the total freshwater inflow to Tampa Bay (Goodwin 1987; Lewis and Estevez 1988).

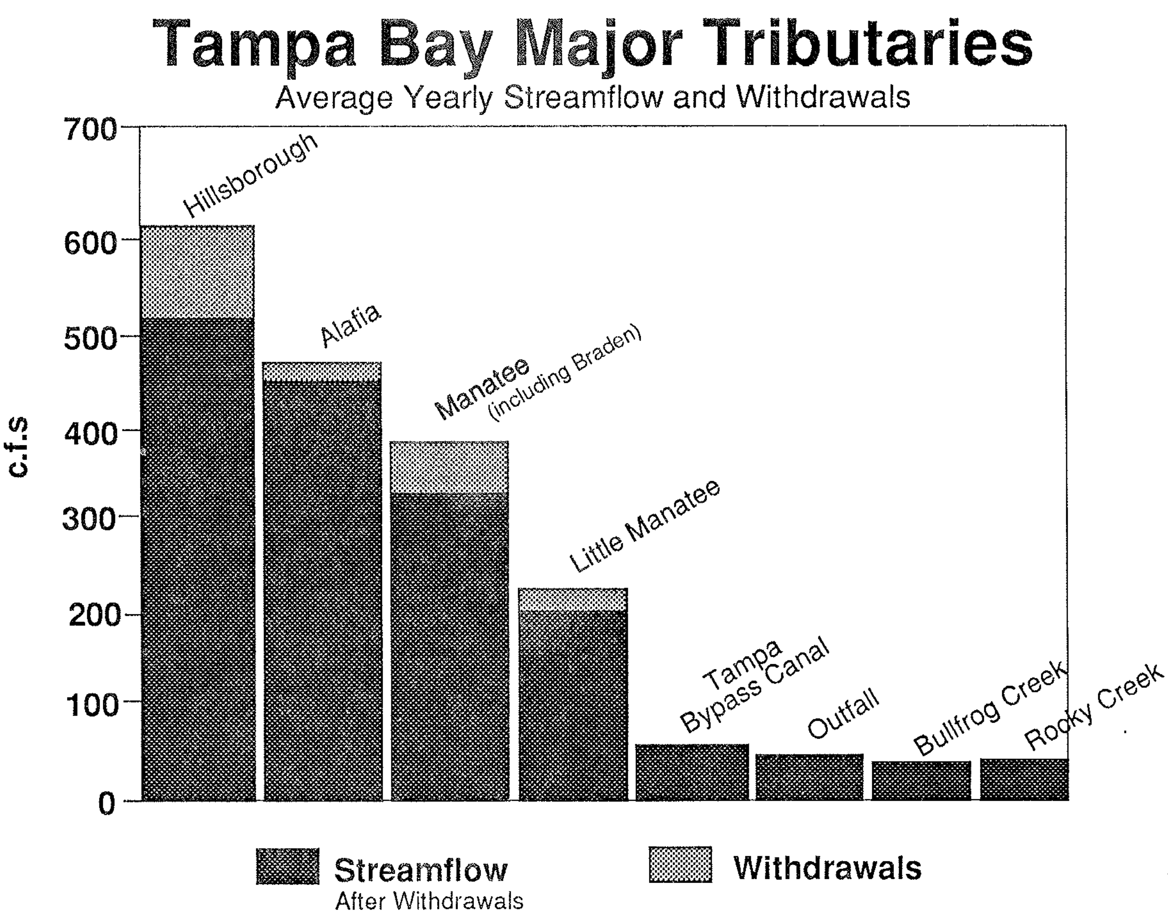

Figure 7. Average yearly streamflow and withdrawals from eight tributaries to Tampa Bay.

Not surprisingly, estimates of total freshwater inflow to Tampa Bay contain terms which involve a considerable level of uncertainty. For instance, streamflow is not measured for most of the minor tributaries to the bay and gauging sites on major rivers are upstream of significant portions of their respective drainage basins. Linear extrapolation using drainage basin areas can be used to estimate flow from ungauged areas, but differences in runoff coefficients may differ and thereby introduce sources of error. Even in areas where streamflow is measured, differences in length of record can introduce bias into estimates of average flows.

Despite these sources of error, estimates of total tributary flow to Tampa Bay have been presented by several authors. Dooris and Dooris (1985) estimated average total flow from seven gauged streams at 1,792 cfs. Goodwin (1987) estimated average total flow to the bay from tributaries at 1,904 cfs, but this also did not include estimates of flow from ungauged streams. Hutchinson (1983) estimated flow from ungauged areas to be 344 cfs, giving a total freshwater inflow of 2,229 cfs to the bay. In this report, I have re-estimated average inflow to the bay by using streamflow data up to 1986 and employing a factor of 81.5 percent for total flow contributed by the four major rivers. This factor is the average of the percentages indicated by Hutchinson (1983) and Lewis and Estevez (1988). Using this formula, my estimate for total tributary flow to Tampa Bay is 2,011 cfs. This estimate accounts for withdrawals made from the bay's tributaries, but does not account for any effluents which enter these streams downstream of gauging stations.

Streamflow Reductions

As shown in Figure 7, withdrawals are taken from the Hillsborough, Manatee, Alafia and Little Manatee Rivers. The Hillsborough and Manatee Rivers are impounded by instream reservoirs and withdrawals are made for municipal water supply. Included in the values for the Manatee River are municipal withdrawals from the Braden River, an impounded tributary to the Manatee which enters the main river 8 miles from the bay. In contrast to these three instream reservoirs, withdrawals from the Little Manatee River are diverted to an offstream reservoir and used for power plant cooling water. Withdrawals shown for the Alafia River are actually taken from artesian springs which flow into the river.

Using values from 1987, average daily withdrawals from these four streams were 93 cfs for the Hillsborough, 50 cfs for the Manatee, 7 cfs for the Braden, 8 cfs for the Alafia and 19 cfs from the Little Manatee. Collectively, these withdrawals are equivalent to 8.8% of the estimated average streamflow to Tampa Bay, suggesting that the impact of these flow reductions may be limited when viewed on a net annual basis. The effects of these withdrawals, however, can be very important seasonally. Also, the refilling of reservoir storage can markedly increase flow reductions during recovery after low flow periods.

Withdrawals and operating schedules for the three instream reservoirs have resulted in the significant reduction of dry season flows in those rivers and, periodically, the virtual elimination of flows past the dams entirely. This is illustrated in Figure 8, where monthly withdrawals and discharge from the Hillsborough River reservoir are plotted for October 1982 to September 1986. During this period discharge from the reservoir averaged 325 cfs, but there were 547 days when daily discharges were less than 20 cfs. Outflows from the Manatee and Braden Rivers are similarly affected by extended low or zero flow periods.

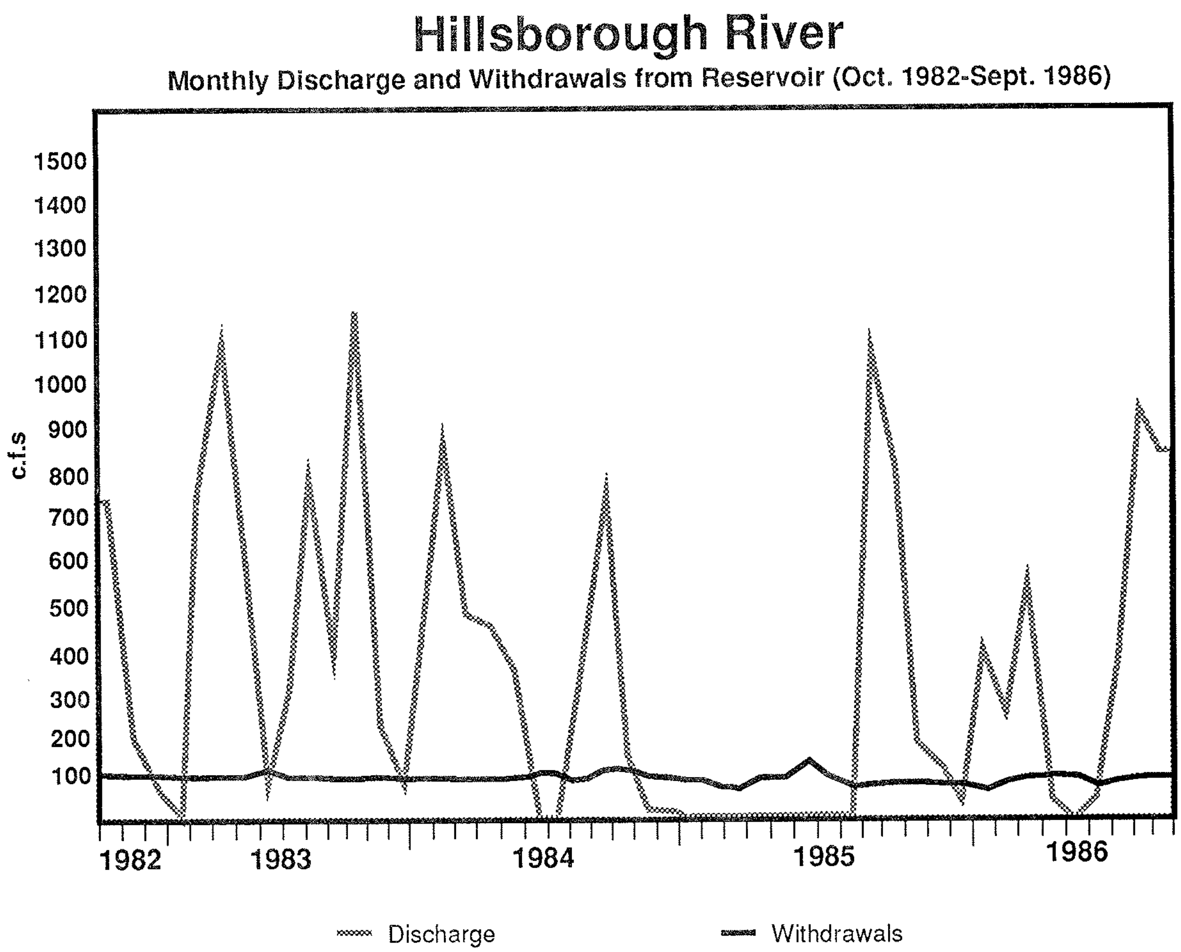

Figure 8. Monthly discharge and withdrawals from the Hillsborough River reservoir.

The impoundment and utilization of these rivers flowing to Tampa Bay has certainly impacted the downstream estuarine environments. The most conspicuous effect of instream reservoirs is the elimination of movement past that point by migratory organisms such as fishes. This is particularly detrimental in estuarine areas where the juveniles of many marine species migrate upstream to utilize low and moderate salinity habitats. The Braden River dam was built in the estuarine zone of that river and functions as a salinity barrier. Also, significant flow reductions and the inducement of prolonged periods of low or zero flow can result in a lack of flushing and exacerbate water quality problems in rivers suffering from eutrophication. Thirdly, flow reductions can disrupt salinity distributions in the downstream estuary and cause salinity changes from dry to wet seasons to be more extreme. The impacts of flow reduction in the Hillsborough River may be somewhat lessened by the discharge from the Hookers Point Advanced Wastewater Treatment Plant, which discharges an average of 51 mgd of tertiary treated effluent near the mouth of the river. Any remedial effects of this freshwater source are probably spatially variable, particularly in the lower river, but it does provide important inflow to Hillsborough Bay in the dry season.

It should be stated that the Hillsborough, Manatee, and Braden River reservoirs were built before there was a great deal of knowledge or concern by the public in the region regarding the importance of freshwater inflows for the management of estuarine resources. In fact, all three reservoirs were constructed before local regulatory agencies had rules regarding the withdrawal and use of surface waters. In 1972, the Florida Water Resources Act established five Water Management Districts who were given the responsibility of regulating the use of water resources in their respective regions. When the Southwest Florida Water Management District established its rules regarding consumptive use in 1975,there was already heavy reliance on these reservoirs for municipal water supply. Since the Tampa Bay area is one of the fastest growing regions in the country, this reliance has only grown through the years. Since the mid-seventies, however, the Southwest Florida Water Management District has addressed the issue of freshwater inflow to estuaries by sponsoring seminars, workshops, literature reviews and several scientific studies. The goal of this involvement has been to better evaluate the freshwater inflow needs of regional estuaries so that future water resource development can be done in a manner more compatible with the management of estuarine resources.

Instream reservoirs are not the only method of surface water storage used for withdrawals in the Tampa Bay area. Just south of the Little Manatee River, the Florida Power and Light Corporation operates a 4,000 acre offstream reservoir which is used for power plant cooling water. Water for this reservoir is diverted from the Little Manatee, but withdrawals can only be made when the river is over a particular seasonal level. Consequently, environmental impacts have been much less than with the three impounded streams. Monthly streamflow and withdrawals from the Little Manatee during 1979 to 1985 are shown in Figure 9. Pumpage from the river generally is highest during mid to late summer, while percentage flow reductions are highest during June and July (Table 1).

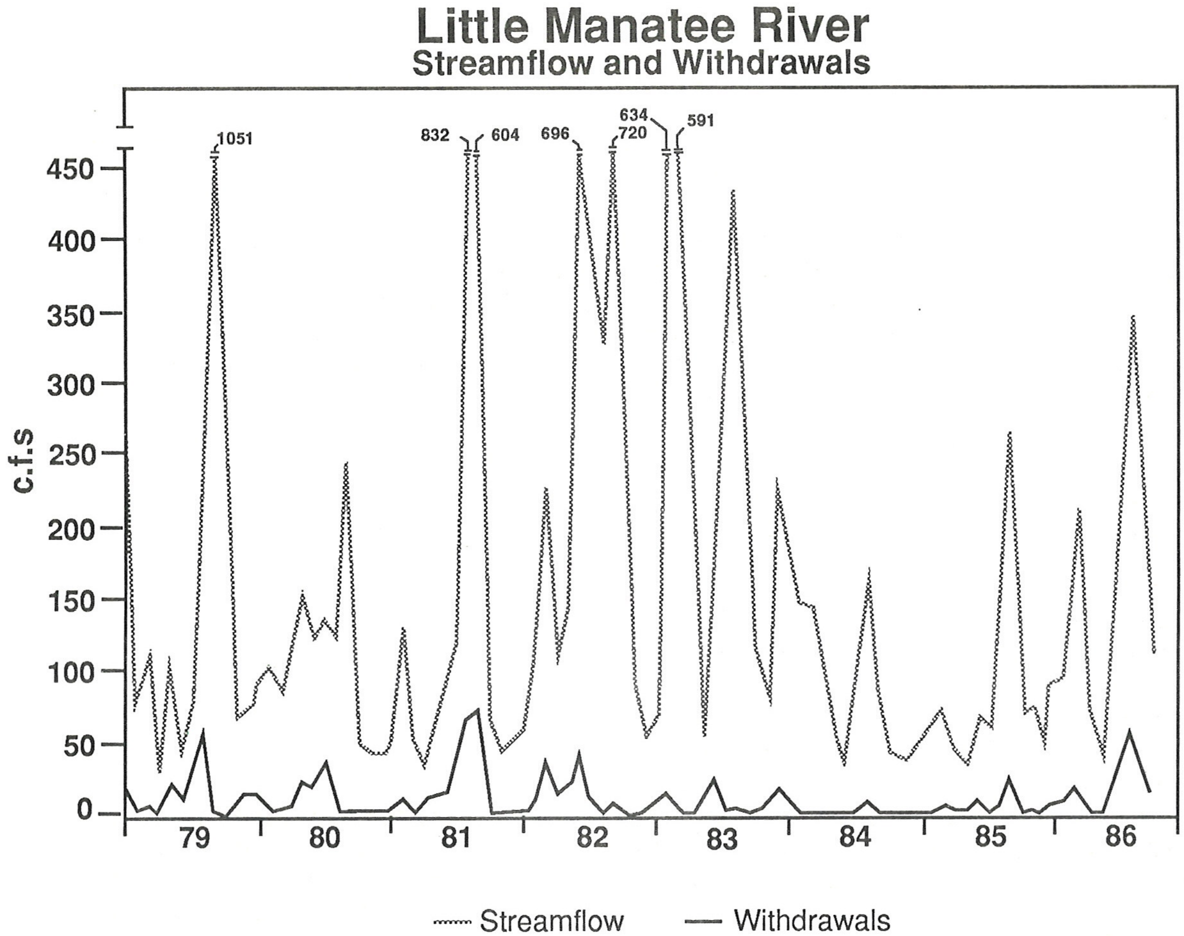

Figure 9. Monthly streamflow and withdrawals from the Little Manatee River. Streamflow is the sum of values from the Wimauma gaging station and withdrawals from the river.

Table 1. Average monthly rates of withdrawals and percentage flow reductions for diversions from the Little Manatee River for the period April 1977 through September 1986.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Withdrawals (cfs)	7	5	8	2	8	14	22	26	15	1	1	4
Percent of flow (%)	5	3	5	4	8	13	14	8	4	1	2	4

FLOOD CONTROL CHANNELS

Tampa Bay receives freshwater flow from a number of flood control channels. These are manmade canals which diverge from natural waterways and are primarily used during intermittent high flow periods. Flows in these canals are controlled by gates which are operated in response to hydrologic conditions. Channel A, which diverts water from Rocky Creek, originates in northwest Hillsborough County and drains to Old Tampa Bay. The Lake Tarpon Outfall Canal, which was built in Pinellas County 1971, drains the Lake Tarpon watershed and also empties into Old Tampa Bay. Flows in this canal, which average 34 cfs, are manipulated to facilitate water level fluctuations in Lake Tarpon and to provide storage in the lake for the summer rainy season.

By far the largest flood control structure in the region is the Tampa Bypass Canal which was constructed between 1974 and 1983. This 19 mile structure which lies east of Tampa is used to divert high flows from the Hillsborough River and prevent flooding in the cities of Tampa and Temple Terrace. The canal originates nearer the Hillsborough River northeast of Tampa and empties into McKay Bay, an arm of Hillsborough Bay, through the channel of the old Palm River. The lower portions of the canal receive flow from groundwater seepage and stormwater runoff, although very high flows in the canal are restricted to diversions from the Hillsborough River. This operating schedule creates hydrographs which are characterized by long periods of relatively stable flows followed by abrupt discharge peaks during periodic wet periods, such as that accompanying Hurricane Elena in 1985 (Figure 10).

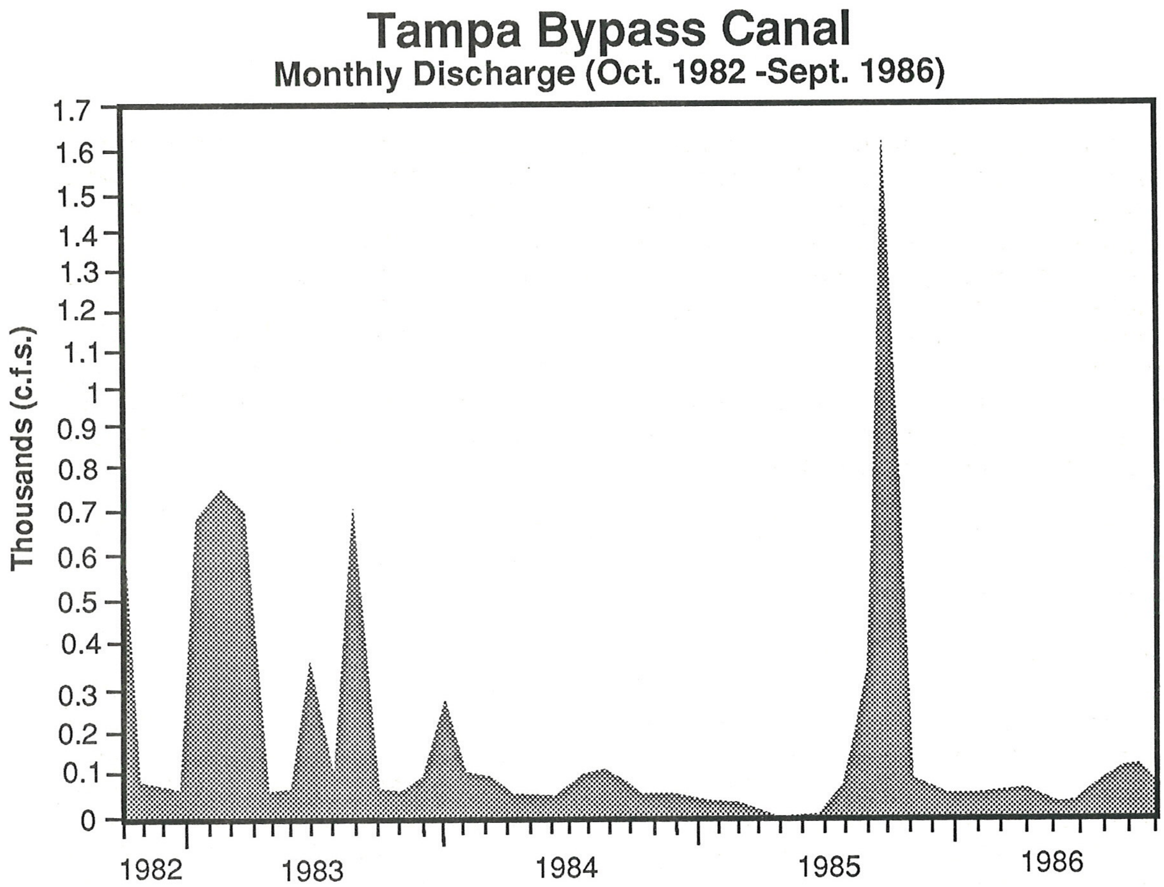

Figure 10. Monthly discharge for the Tampa Bypass Canal.

WATER QUALITY

A review of water quality in streams flowing to Tampa Bay can be quite extensive depending on the detail of the review. Dooris and Dooris (1985) in their review of the quantity and quality of surface flows to Tampa Bay discussed twelve stations for which water quality sampling had been conducted on a regular basis. Other data exist from a number of independent studies,but these data generally cover brief time periods and are not available from a centralized data base. The review of the Tampa Bay watershed by Drew, et al. (in review) identifies and reviews many of these miscellaneous sources of data. Much of the information presented here was synthesized from the review of Drew, et al. (in review). Since the effects of stormwater runoff and industrial or municipal discharges are discussed in other chapters of these proceedings, these topics are treated only lightly here.

In general, streams flowing to Tampa and Sarasota Bays are characteristic of the Florida coastal plain. They are generally high in color, rich in nutrients, often of sluggish flow, and have seasonally fluctuating dissolved oxygen levels due to changes in temperature, metabolic activity, and the loading of oxidizable materials from the watershed. These streams generally transport low sediment loads due to low surface relief within the watershed and a lack of fine grained materials in surface soils throughout the region. In addition, virtually all streams flowing to the bays have been impacted adversely by urban development or agriculture with varying effects on their water quality.

Water quality data for a number of tributaries to Tampa and Sarasota bays are listed in Table 2. These tributaries were selected to represent a range of sizes, flows, and impacts due to urban or agricultural development. Where possible, data from the most downstream station above the tidal reach are listed. As indicated in Table 2, however, some data are from brackish zones and an influence of the bay on water quality is apparent. A geographic approach is used for discussion of these data, beginning with the western shore of Tampa Bay and proceeding clockwise.

Pinellas County

The southern half of the Pinellas County peninsula exhibits low surface relief with a maximum elevation of approximately 25 feet. Consequently, no streams of considerable size are found in this region and drainage is through stormwater drainage systems, bayous, and tidal creeks. Tributaries to Boca Ciega Bay west of Tampa Bay have been modified to underground storm sewers or open ditches. Similarly, the southeastern portion of the peninsula is drained by ditches and storm sewers which empty into small tributaries and bayous of lower Tampa Bay. Lopez and Giovannelli (1984) monitored three small creeks in the south Pinellas region. Water quality data collected during storm events for one of these creeks, Booker Creek, are listed in Table 2. Baseflow in these south Pinellas creeks was extremely low, ranging from .57 to 1.0 cfs, and the majority of nutrient loading to the bays occurred during periodic storm events.

Five small streams draining mid Pinellas County flow easterly to Old Tampa Bay. Land use in this region is predominantly urban and at least 30% of the area is drained by storm sewers. Water quality data for these five creeks are limited to portions of Allen and Alligator Creeks (Table 2). Both creeks exhibit wide fluctuations in dissolved oxygen levels and high concentrations of nutrients, BOD, and coliform bacteria.

Lake Tarpon and Northwest Hillsborough County

From the north, Old Tampa Bay receives flow from three drainage areas; Brooker Creek/Lake Tarpon Outfall Canal, Double Branch Creek, and the area of northwestern Hillsborough County drained by Rocky and Sweetwater Creeks. The Brooker Creek/Lake Tarpon drainage basin is one of the most unique systems in the region. Until 1969, Lake Tarpon was

Tributary	Period	N[1]	Total P	Total N	Organic N	NO_3+ NO_2	NH_3 N	Color	BOD	Source
1. Booker Creek[2]	07/75-05/80	11	0.50	2.40	2.10	0.16	0.14	--	4.9	Lopez & Giovannelli 1984
2. Allen Creek[2]	07/75-05/80	28-34	0.52	2.40	1.80	0.45	0.22	--	5.6	Lopez & Giovannelli 1984
3. Alligator Creek	10/83-09/85	13	0.45	1.36	0.93	0.29	0.14	--	2.0	USGS 1986a, 1986b
4. Lake Tarpon	10/83-09/85	12	0.06	0.65	0.47	0.09	0.09	55	--	USGS 1986a, 1986b
5. Double Branch Creek[3]	01/84-12/85	24	0.33	1.19	0.98	0.06	0.14	80	1.7	HEPC 1986
6. Rocky Creek (upper)	10/83-09/85	12	0.78	1.27	0.67	0.47	0.13	--	--	USGS 1986a, 1986b
7. Sweetwater Creek[3]	01/84-12/85	24	0.31	1.33	0.89	0.19	0.25	32	1.7	HEPC 1986
8. Gandy Blvd. Ditch[2]	07/75-05/80	20	0.30	0.76	0.66	0.24	0.40	--	5.0	Lopez & Giovannelli 1984
9. Hillsborough R. (Fowler Ave.)	10/83-09/85	12	0.34	1.06	0.66	0.37	0.04	55	--	USGS 1986a, 1986b
10. Hillsborough R. (S.R. 585)	01/84-12/85	24	0.36	1.17	0.93	0.11	0.13	43	1.8	HEPC 1986
11. Tampa Bypass Canal	01/84-12/85	24	0.54	1.50	1.19	0.11	0.20	24	3.4	HEPC 1986
12. Delaney Creek[3]	01/84-12/85	24	2.67	24.10	4.00	9.70	11.30	67	5.1	HEPC 1986
13. Alafia River	01/84-12/85	24	2.40	1.87	0.49	1.30	0.08	39	0.08	HEPC 1986
14. Little Manatee R.	01/84-12/85	24	0.38	1.32	0.60	0.63	0.09	52	1.3	HEPC 1986
15. Manatee R. (upper)	10/83-09/85	4	0.29	0.44	0.34	0.04	0.05	65	1.1	USGS 1986a, 1986b
16. Manatee R. (reservoir site 1)	01/84-12/85	24	0.21	0.91	0.71	0.10	0.10	131	2.5	Manatee Co. Unpubl. data
17. Manatee R.[3] (lower zone 3)	02/82-03/83	12	0.20	1.43	1.28	0.11	0.04	--	1.8	Manatee Co. & Camp, Dresser & McKee, Inc. 1984
18. Whitaker Bayou[3]	01/84-12/85	6-9	1.53	6.14	2.37	0.24	3.53	--	--	Sarasota Co. 1985, 1986
19. Phillippi Creek	01/84-12/85	6-9	0.97	2.98	1.20	1.03	0.75	--	--	Sarasota Co. 1985, 1986

All units expressed as mg/l except color (Pt-Co units).

[1]Number of observations.
[2]Stormwater runoff samples, flow-weighted average.
[3]Brackish stations.

Table 2. Mean concentrations of selected nutrients for nineteen tributaries to Tampa and Sarasota Bays.

hydraulically connected to the brackish Anclote River to the west through a sinkhole in its northwestern end and salinities in the lake fluctuated widely. In 1969 a dike was built separating the sink from the lake, resulting in a rapid drop in salinity and nutrient levels (Bartos, Rochow, and Courser 1977). After removal of the sink, Brooker Creek became a more dominant factor influencing the lakes limnology. Brooker Creek drains 42 square miles which is characterized by wetlands, citrus groves, and numerous lakes. The Lake Tarpon drainage basin including Brooker Creek is about 11% urban development with the remainder split between wetlands and agriculture. Water quality in the lake is relatively good with moderately high nutrient levels, but recent blooms of blue green algae have caused concern. As previously mentioned in the hydrological discussion, outflow from Lake Tarpon is through the Lake Tarpon Outfall Canal which runs south and southeast to Old Tampa Bay. Assuming that nutrient concentrations in the outfall canal are similar to those in the lake, levels of nitrate, ammonia, and phosphorus are low compared to other streams in the region (Table 2).

To the east of Lake Tarpon lies Double Branch Creek which drains a small watershed (19 sq. mi.) at the northern end of the bay. Near its mouth the creek is in good physical condition with adjacent tidal marshes intact, but high nutrient and bacteria concentrations are found during the wet season due to upstream urban and pastureland runoff. Perturbations to this creek are much less than for the creeks immediately to the east, however, and high color values indicate the influence of wetlands in this drainage basin.

Rocky and Sweetwater Creeks drain northwestern Hillsborough County including parts of the City of Tampa and both of these basins have experienced rapidly increasing urbanization. Both streams are channelized near their mouths and are inter-connected upstream by a flood control conduit, "Channel G". Another flood control facility, "Channel A", diverges off from Rocky Creek 4.4 miles above its mouth and also flows to the bay. Salinity barriers were constructed in Rocky Creek and Channel A during 1977-78. Water quality in both Rocky and Sweetwater Creeks has been seriously affected by stormwater runoff and municipal wastewater discharges, resulting in low dissolved oxygen and high levels of coliform bacteria and nutrients, particularly nitrogen species (Table 2).

South from Sweetwater Creek to the tip of the Interbay Peninsula lies the City of Tampa and the remaining drainage to Old Tampa Bay. Drainage from this urban area is through underground storm sewers and ditches to the bay. One of these drainage systems, the Gandy Boulevard Drainage Ditch, was monitored by Lopez and Giovanelli (1984), who found that total nitrogen and phosphorus were highest in the baseflow sample, but that the majority of nutrients, BOD, and lead were contributed to the bay during storm events.

Hillsborough River

The Hillsborough River, which enters Hillsborough Bay in the center of downtown Tampa, comprises the largest and most diverse basin draining to Tampa Bay. All totaled, land use in the Hillsborough River basin is estimated at 54% agricultural, 14% range, 13% wetlands, and 15% urban.

The drainage basin for the upper Hillsborough River (headwaters to Fletcher Avenue) is primarily agricultural, range, or wetlands as the small towns of Zephyrhills and Plant City are the only urban centers in the basin. At least ten principal tributaries enter the upper river including Crystal Springs, which provides baseflow during dry periods. Without going into detail, water quality in several of these tributaries has been degraded by agricultural runoff and various industrial or municipal discharges. The main channel of the upper river, however, is in excellent condition, as the floodplain is largely protected under public ownership, and no point source discharges occur on its shore. Cypress Creek, a major tributary of the Hillsborough, enters the river just above the City of Tampa. This creek drains extensive wetlands and contributes water to the river that is high in color and relatively low in nutrients, BOD, and bacteria. Due to the assimilative capacity of the upper river and the influence of Cypress Creek, water quality problems observed in various upstream tributaries are largely unapparent downstream. Where it flows into the City of Tampa, the Hillsborough River has good water quality characterized by high levels of color and dissolved organic carbon and relatively low levels of nutrients, turbidity, and coliform bacteria (Table 2).

Once the river reaches Fletcher Avenue it quickly takes on the characteristics of an urban river. Seven miles downstream from Fletcher Avenue the river is impounded, creating a long, narrow reservoir which is surrounded by the cities of Tampa and Temple Terrace. Lands draining to this reservoir are approximately 75 percent urban and 25 percent open space. Stormwater from this area, however, averages only five percent of the net inflow to the reservoir with the remainder supplied by the river (Priede-Sedgwick, Inc., 1980). Principal water quality problems in the reservoir are high nutrient and metal concentrations, low dissolved oxygen in deeper waters, dense growths of water hyacinths and periodic blooms of blue green algae. Algal blooms are most common in spring and early summer when flows are low, residence time is long, and temperatures are increasing (Metcalf and Eddy, Inc., 1983).

The lower Hillsborough River consists of the 11 mile, tidally-affected reach downstream of the dam. The lower river receives freshwater inflow from reservoir releases, stormwater runoff, and Sulphur Springs, an artesian spring that averages 40.8 cfs discharge. The immediate basin for the lower river is approximately 40 square miles in size, intensely urban, and primarily drained by storm sewers. Water quality in the lower river is controlled by inflow from the reservoir and stormwater runoff, but the effects of stormwater vary considerably between seasons and among parameters. Coliform bacteria and heavy metals in the river show the closest response to urban runoff in either the dry or wet seasons. Phosphorus contributions from stormwater are comparatively small, averaging six to ten percent of the total load to the river with the remainder coming from upstream sources. Stormwater, however, is a significant source of suspended solids, BOD, and total nitrogen to the lower river, particularly during the dry season when it may account for 37 to 40 percent of the seasonal load (see Drew et al. in review).

The lower river periodically experiences problems with low dissolved oxygen which result from excessive algal activity, sediment oxygen demand, sluggish flows and tidal salinity effects. Low dissolved oxygen levels are closely tied to the location of the salt wedge and during the dry year of 1981 were particularly low. Freshwater flow suppresses tidal and diurnal (algal) effects on dissolved oxygen fluctuations and generally increases the rivers DO concentrations, particularly at low to moderate flows. Low DO has been found near the dam during high flows, however, when oxygen poor bottom waters from the reservoir are released through lower control gates.

Delaney Creek

South of the Tampa Bypass Canal, Delaney Creek drains approximately 16 square miles of land which is experiencing rapid urbanization. A number of industrial point sources discharge into Delaney Creek resulting in very poor water quality. Extremely high concentrations of nitrogen species in the creek (Table 2) are due to discharges from Nitram, Inc., a nitrogen fertilizer processing plant.

Alafia River

Of the major rivers flowing to Tampa Bay, the Alafia River is notable for its poor water quality. The Alafia drains lands which overlie rich phosphate-bearing deposits and extensive phosphate mining has occurred in the watershed. Although water quality in the Alafia River has been affected by agricultural runoff and miscellaneous point source discharges, impacts associated with phosphate mining, processing, and enrichment have been the overwhelming perturbations.

Although perturbations to the river still occur, impacts to water quality from the phosphate industry are generally not as severe today as in past decades. Prior to the mid-1970's, the discharge of poorly treated or untreated effluents from mines and phosphate or chemical processing plants caused extreme loadings of phosphorus, fluoride, sulfate, ammonia and acids to the river. During this period the Alafia was particularly notorious for high concentrations of phosphorus and fluoride. For instance, between 1959 and 1966, total phosphorus concentrations commonly ranged between 10 and 30 mg/l in the main stem of the river while fluoride concentrations were generally greater than 10 mg/l (Hand, Tauxe and Watts 1986). Water quality in the Alafia basin has historically been worst in the North Prong of the river due to the abundance of phosphate and chemical processing plant discharges.

Although it has been extensively mined and is also characterized by high constituent levels, the South Prong has had significantly better water quality than the North Prong. Water quality below the confluence of the North and South Prongs has generally been intermediate between these two branches.

Water quality in the Alafia river basin has shown significant improvement since the mid-1970's due to the implementation of pollution abatement practices by the phosphate industry in response to federal, state, and local regulations. The recycling and better management of waste effluents plus an elimination of slime-pond spills have resulted in significant reductions in constituents such as total phosphorus, orthophosphate, and fluoride. Nutrient levels are still extremely high in the river (Table 2), however, and the Alafia is a major source of nutrients to Tampa Bay. Data collected during 1979 indicate that since the initiation of advanced wastewater treatment at the Hookers Point STP, the Alafia has become the predominant source of both total nitrogen and phosphorus to Hillsborough Bay (see Garrity, McCann and Murdoch 1985).

Flowing into the Alafia River fourteen miles above its mouth is Lithia Springs, an artesian system that discharges groundwater at an average rate of 46 cubic feet per second. Water quality in the spring reflects groundwater conditions, with excellent water clarity and a nearly constant temperature year round ($75^{o}F$). An interesting aspect of the spring's water chemistry is its high nitrate concentrations, which ranged from 2.3 to 3.2 mg/l during 1984-1986. Crystal Springs, which flows into the Hillsborough River, similarly show high nitrate levels, averaging 1.8 mg/l during this same period. These data indicate that at some locations in Hillsborough County high nitrate groundwaters may have a pronounced influence on instream concentrations. Stream-groundwater relationships in the region are complex, however, and it is difficult to assess how widespread this phenomenon might be. Similarly, the causes of high nitrate concentrations in these two springs are not known, and the regional extent of this condition is poorly documented.

Little Manatee River

The Little Manatee River is the smallest of the four major rivers draining to Tampa Bay and is generally considered to be the one in the best ecological condition. Land use in the basin is primarily agricultural with light urban development occurring on two small tributaries and at the town of Ruskin near the mouth of the river. The floodplain of the river in the middle and upper reaches is largely intact and mangroves or saltmarsh line the shore of much of the lower river.

Water quality in the upper reaches is generally high in color with moderately high nutrient levels, presumably due to agricultural, highway and wetland runoff. One phosphate mine, which is currently inactive, has a permitted discharge into the headwaters of the river. Nutrient inputs from undisturbed soils and vegetative associations are uncertain, however, so the effects of land alteration on background nutrient levels are difficult to assess. Values for selected water quality parameters for a station 15 miles above the river mouth are presented in Table 2. This station is about four miles upstream of the maximum penetration of brackish water during the dry season and represents the majority of inflow to the lower river and Tampa Bay from the watershed. Water quality at this station is similar to the upstream reaches, except for nitrate concentrations which are markedly greater downstream. The most common water quality problem in the Little Manatee River is periodic high counts of coliform bacteria. Low fecal coliform to fecal streptococcus ratios indicate non human contamination, possibly from feedlots, dairies, or fish farms (see Drew et al. in review).

Although nutrient levels in this river are somewhat elevated and significant withdrawals are taken from the river by a local power plant, the Little Manatee probably best represents the natural ecological interactions of a river and its watershed with Tampa Bay. For that reason, the Little Manatee River will be the subject of investigation for the next two years in a study supported by NOAA's coastal grants program locally administered by the Florida Department of Environmental Regulation. This study will examine runoff (streamflow) quantity and quality at several sub-basins within the watershed and compare these to land use, soils, vegetation and topography in each sub-basin. In the estuary the response of fish, zooplankton, phytoplankton, salinity, water chemistry and limiting nutrient conditions will be related to seasonal changes in freshwater inflow. It is hoped that this study will enable local planners and resource managers to better evaluate the impacts of human activities in a watershed to its receiving estuary and, therefore, approach the goals of estuarine management from a basin-wide perspective.

Manatee River

The drainage basin for the Manatee River is primarily in range (41%) and agricultural (38%) land uses. The lower portion of the river, however, is heavily urbanized as it flows between the adjacent cities of Palmetto and Bradenton. The river is impounded for municipal water supply 24 miles above its mouth. Water quality in the upper river above the reservoir is generally good, but periodic high levels of phosphorus, ammonia and coliform bacteria, however, indicate that agricultural runoff is a significant nutrient source. Water quality data from the Manatee River reservoir serves as the most downstream station above the lower river. Based on the limited data presented in Table 2, reservoir water is higher in nitrogen species and organic color than that of the upper river.

Below the dam, Gamble Creek and the Braden River are the major tributaries to the river. Gamble Creek experiences high concentrations of nutrients and coliforms after heavy rains apparently due to pastureland runoff. The Braden River is the largest tributary to the Manatee, and its basin is largely in agriculture -- mainly range, improved pasture, and cropland. The Braden enters the Manatee 8 miles above its mouth, and similarly is impounded for municipal water supply. Downstream of the dam the Braden River is estuarine, with salinities ranging from 14 to 26 ppt in the dry season to 0 to 19 ppt in the wet season (E.D. Estevez, pers. comm.).

Virtually all of the Manatee River below its reservoir is tidally affected and brackish water (>1,000 umhos) comes within three miles of the dam during the dry season. The zone of maximum mixing of fresh and salt water occurs from 9 to more than 18 river miles above the bay depending on seasonal flow. The river below the dam is characterized by moderately high nutrient levels, periodic algal blooms and seasonal problems with low dissolved oxygen. A study of this portion of the river by Manatee County and Camp, Dresser, and McKee, Inc. (1984) examined water quality in four ecological zones of the lower river. The zone nearest the mouth had the lowest concentrations of nutrients, chlorophyll, and coliform bacteria due to the flushing action of lower Tampa Bay, a region of the bay with good water quality. In the nine mile zone nearest the reservoir, average nutrient concentrations were moderately high, but maximum recorded levels of TKN (8.0 mg/l), ammonia (.33 mg/l), pH (9.1) and chlorophyll (60 ug/l) were very high, indicating occasionally poor water quality conditions. Instantaneous dissolved oxygen concentrations in this zone were periodically below state water quality standards (4.0 mg/l).

Another area of the lower river that has periodic water quality problems is from the mouth of the Braden River downstream to the main bridge between the towns of Palmetto and Bradenton. The City of Bradenton's wastewater treatment plant and a citrus processing plant discharge into this portion of the river, and these effluents may be also transported up the Braden River on flooding tides. Violations of state water quality standards were most numerous in this portion of the river with violations for dissolved oxygen concentrations being most common. Mean nutrient concentrations were moderately high (Table 2), but maximum concentrations of TKN (5.99 mg/l), ammonia (.54 mg/l), chlorophyll (182 ug/l), and pH (9.37) were very high indicating periodic water quality problems. In general, water quality in the lower Manatee River is appreciably degraded and suffers from the effects of point source discharges, agricultural and urban runoff, and seasonally important streamflow reductions.

Sarasota Bay

To various degrees, all tributaries to Sarasota Bay have been channelized or otherwise modified to facilitate stormwater drainage. Water quality data are available for three of these tributaries including the two largest drainage systems, Whitaker Bayou and Phillippi Creek. Nutrient concentrations are very high near the mouth of Whitaker Bayou due to discharges from the City of Sarasota's wastewater treatment plant (Table 2). The plant discharged an average of 8.3 mgd of secondarily treated effluent during 1987, but all discharge to the bayou is scheduled to be discontinued in late 1988. Phillippi Creek, which is highly channelized, similarly receives domestic wastewater discharges in addition to stormwater runoff. Nutrient concentrations, particularly those for nitrogen species, are high for the station listed in Table 2, but greater concentrations are found upstream closer to point source discharges.

WATER QUALITY SUMMARY

Tampa Bay Tributaries

Overall, tributaries to Tampa Bay contain high levels of nutrients. Mean total phosphorus values for the tributaries listed in Table 2 ranged from .30 to .77 mg/l, with the exception of the Alafia River and Delaney Creek which had mean values of 2.4 and 2.7 mg/l. For the remaining tributaries, phosphorus values were highest for those systems which have been impacted by urban runoff or point source discharges. Although affected by varying degrees of pollution, three river stations --Hillsborough at Fowler Avenue, Little Manatee, and upper Manatee-- probably represent the three least impacted sites listed in Table 2. Mean total phosphorus concentrations for these three stations ranged from .29 to .38 mg/l.

The concentration of nitrogen species in tributaries to Tampa Bay is particularly important because evidence indicates that algal production in the bay is primarily nitrogen limited. With the exception of Delaney Creek, mean ammonia concentrations in Table 2 ranged from .05 to .40 mg/l, with the highest values reported from tributaries receiving point source discharges (Rocky, Sweetwater) or large quantities of urban runoff. As with total phosphorus, mean nitrate concentrations for the Alafia River (1.23 mg/l) and Delaney Creek (9.7 mg/l) were exceptionally high compared to other stations, which ranged from .06 to .63mg/l.

Organic nitrogen values listed in Table 2 ranged from .34 to 2.1 mg/l, with the highest values reported from Delaney Creek and two of the small urban creeks studied by Lopez and Giovannelli (1984). Mean organic nitrogen concentrations for the remaining non-tidal stations were less than 1.0 mg/l. Total nitrogen values were similarly highest for two of the urban creeks and Delaney Creek, but were also high for the Alafia River. With the exception of Delaney Creek and the Alafia and Little Manatee Rivers, organic nitrogen comprised the majority of mean total nitrogen, ranging from 56 to 87 percent. For Delaney Creek and the Alafia River, total nitrogen concentrations were strongly influenced by high nitrate concentrations, and organic nitrogen averaged 16 and 26 percent of total nitrogen, respectively.

Nutrient Loading Estimates

Nutrient loading estimates can be calculated for tributaries where streamflow and water quality data are available. These estimates are valuable for they quantify nutrient loading to various portions of the bay and provide a measure against which to assess the impacts from stormwater runoff or point source discharges. However, due to the inadequacies of limited available data, nutrient loading estimates are rough approximations and the degree of possible error varies greatly between streams. Acknowledging a certain level of uncertainty, nutrient loading estimates for eight tributaries to Tampa Bay were made by Dooris and Dooris (1985), and large differences in nutrient loading between streams were found. Using more recent water quality data, I have re-estimated average annual loading of selected nutrients to Tampa Bay for the tributaries examined by Dooris and Dooris with the exception of Sweetwater Creek. These nutrient loading estimates were calculated from the long term average streamflow averages depicted in Figure 7 and the mean nutrient values for 1984-85 listed in Table 2.

These estimates generally supported the tributary ranking by nutrient load presented by Dooris and Dooris, but there were some notable differences in the results, in particular: greater organic nitrogen and nitrate loadings for the Hillsborough and Little Manatee Rivers and Rocky Creek; reduced nitrate loading for the Manatee River; and reduced phosphorus loading for the Alafia, Hillsborough, Manatee, and Little Manatee Rivers. However, in many cases these two analyses used different water quality stations and methods for computing total stream discharge; therefore, some differences in the results are expected. Due to differing methodologies, these two studies cannot be compared to identify trends over time, which would require more in-depth analysis of each tributary.

It is also emphasized that these recent estimates, and many of those presented by Dooris and Dooris, are biased for nutrient loading above the brackish portion of each river and nutrient additions to the lower reaches of the rivers are largely ignored. For some tributaries (e.g., Manatee River and Rocky Creek), these downstream nutrient additions are particularly high, and reported nutrient loads seriously underestimate final nutrient loading to the bay. Since most of the localized nutrient loading to these lower tributary reaches is from stormwater runoff or point source discharges, a separate analysis of those factors may account for their effects.

The seven tributaries for which nutrient loading estimates are made are listed in Table 3 by their average ranking based on loadings of total phosphorus and total nitrogen. The Alafia River has the highest estimated loading rates for these two parameters and nitrate. This was particularly pronounced for total phosphorus, as the estimated annual load for the Alafia was more than five times greater than the value for the next highest river. Similarly, the phosphorus load for the Alafia was 71% of the total load for the seven listed tributaries.

The four major rivers were more closely grouped for estimated total nitrogen loads, with values ranging from 2.7×10^5 kg/yr for the Little Manatee to 8.6×10^5 kg/yr for the Alafia. Loading estimates for organic nitrogen were even more closely grouped, ranging from 1.2×10^5 kg/yr to 3.2×10^5 kg/yr, with the Hillsborough and Manatee Rivers having the highest values. The results for nitrate loadings were similar to total phosphorus in that the Alafia had markedly higher values than the other tributaries due to its high nitrate concentrations.

	AVERAGE ANNUAL LOADING (Kg/Year)			
Tributary	Total P	Total N	Organic N	NO_2+ NO_3
Alafia River (14) and Lithia Springs	$9.2x10^5$	$8.6x10^5$	$1.9x10^5$	$6.4x10^5$
Hillsborough River (9)*	$1.7x10^5$	$5.2x10^5$	$3.2x10^5$	$1.8x10^5$
Manatee River (16)*	$6.9x10^4$	$3.0x10^5$	$2.3x10^5$	$3.3x10^5$
Little Manatee River (15)	$7.9x10^4$	$2.7x10^5$	$1.2x10^5$	$1.3x10^5$
Tampa Bypass Canal (12)	$2.7x10^4$	$7.6x10^4$	$6.0x10^4$	$5.5x10^3$
Rocky Creek (6)*	$2.6x10^4$	$4.2x10^4$	$2.2x10^4$	$1.5x10^4$
Lake Tarpon Outfall (4)	$2.2x10^3$	$2.4x10^4$	$1.7x10^4$	$3.3x10^3$

Table 3. Estimated average annual loading of selected nutrients for seven tributaries to Tampa Bay. Numbers in parentheses refer to water quality stations in Table 2 used for computation. For tributaries denoted by an asterisk (*), results should be viewed with caution, as they do not account for substantial downstream nutrient additions.

In total, the seven tributaries listed in Table 3 are estimated to contribute an average of 1.95×10^5 kg/yr total nitrogen and 1.35×10^5 kg/yr total phosphorus to Tampa Bay, reiterating that this does not account for substantial nutrient additions to the lower reaches of certain rivers. These summed nutrient loading values gives a nitrogen/phosphorus ratio of 1.6, indicating that tributary inflow to the bay is very phosphorus enriched. Much of this is due to the enormous phosphorus load of the Alafia River. The ratio of summed nitrogen and phosphorus loadings for the other six tributaries is 3.3, which still indicates freshwater rich in phosphorus. Fanning and Bell (1985) similarly reported that Tampa Bay is considerably enriched in phosphorus, but stated that causes for this may be complex, involving leaching of phosphate beds, agricultural runoff, point source discharges, etc.

CONCLUSIONS

An evaluation of tributary nutrient loading and its effect on bay water quality is one of the most important aspects of bay management. This chapter has reviewed the streamflow and water quality characteristics of tributaries to Tampa and Sarasota Bays but has not specifically considered their relationships to bay water quality. That topic is discussed in the review of water quality presented later in these proceedings. Instead, the emphasis here is that tributaries to Tampa and Sarasota Bays must also be managed for their own values, i.e., the tidal creek and river habitats upstream of their mouths. Collectively, tributaries to these bays include hundreds of miles of low and moderate salinity habitats. These tidal habitats are normally heavily vegetated by intertidal marshes or mangrove swamps, and are important nursing grounds for many of the bays' most valuable fishery species. If these areas are to maintain their biological function, various physical and chemical perturbations, such as channel and shoreline alterations, freshwater inflow disruptions and nutrient loading from point and non-point sources, must be controlled. The Surface Water Improvement and Management Act passed by the Florida Legislature specifies that Tampa Bay and its tributaries are priorities for conservation, management, or restoration. The assessment of Tampa Bay's tidal creeks recently published by the Tampa Bay Regional Planning Council (1986) suggested guidelines for improved tributary management. Other state and local agencies have sponsored water quality or ecological studies on tributaries in the region. With the current level of knowledge and commitment, the management of tributaries to Tampa and Sarasota Bays should be much improved over previous years. With continued population growth, however, management efforts must be persistent if environmental qualities are to be preserved or in some cases restored.

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CIRCULATION OF TAMPA AND SARASOTA BAYS

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INTRODUCTION

Before addressing the subject of circulation in Tampa and Sarasota Bays, it is appropriate to place these two coastal water bodies in physical perspective with another well-known estuarine system, San Francisco Bay. Figure 1 shows the plan view of each of these three bay systems to the same scale and also gives the names of major sub-embayments or defined sub-units. For purposes of this article, San Francisco Bay is defined to include South, Central, San Pablo, and Suisun Bays. Tampa Bay includes Lower, Middle, Old Tampa, and Hillsborough Bays. Table 1 lists several physical attributes of each bay system. San Francisco Bay is the largest in every category, with Sarasota Bay often at least one order of magnitude smaller. Tampa Bay has about 25% less surface area than San Francisco Bay. It is also more shallow and has less than half the tidal range. San Francisco Bay receives more than 12 times the average freshwater inflow of Tampa Bay and 1,000 times that of Sarasota Bay.

Table 1. Physical attributes of Sarasota, Tampa, and San Francisco Bay.

Physical Attribute	Sarasota Bay	Tampa Bay	San Francisco Bay
Surface area (sq. mi.)	54	347	440
Average depth (ft)	5	12	19
Tidal range (ft)	1.3	2	5
Volume (sq. mi-ft)	270	4,140	8,440
Tidal prism (sq. mi-ft)	70	760	2,010
Average annual inflow volume (sq. mi-ft)	27	2,150	26,500

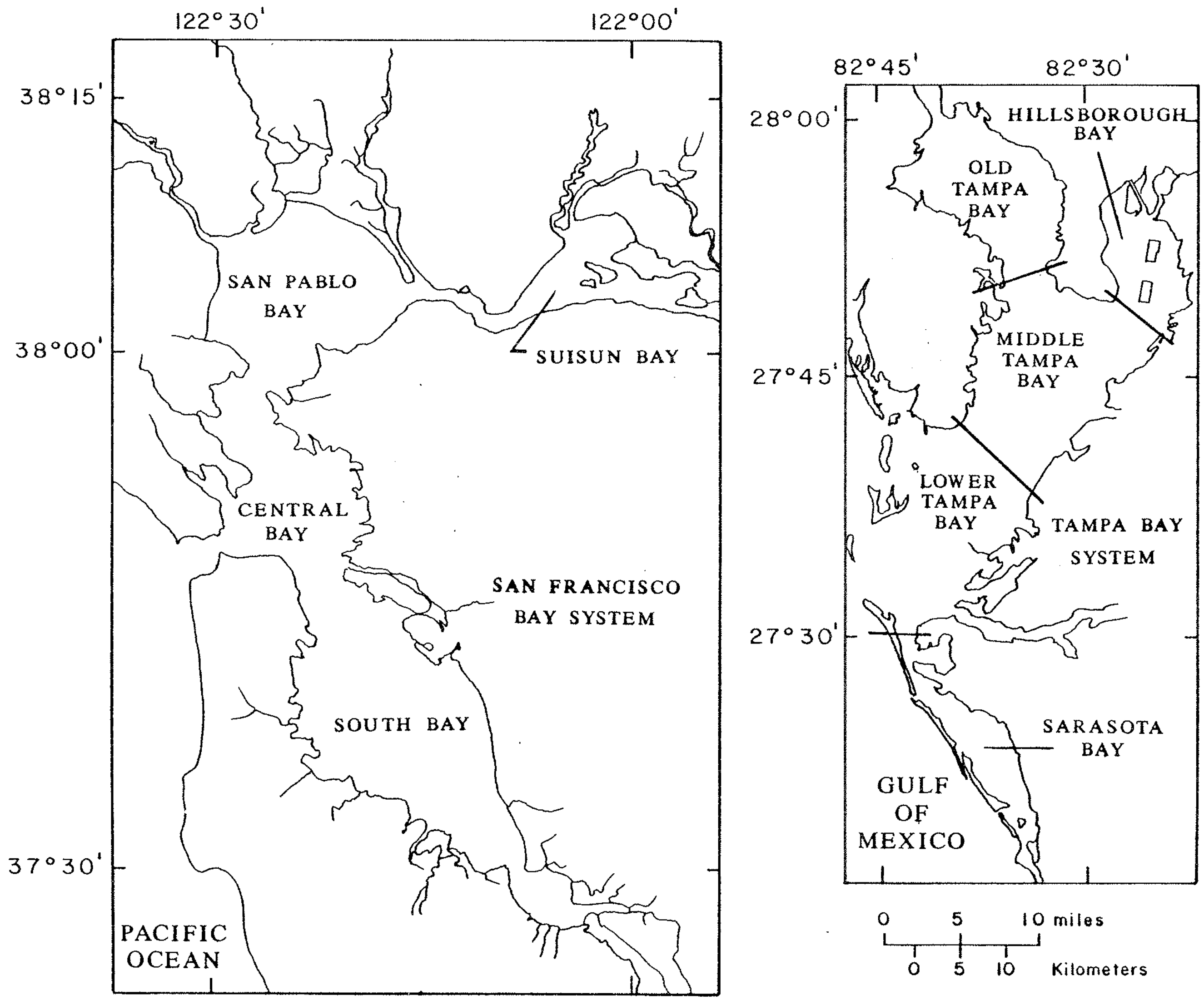

Figure 1. Size comparison of Sarasota Bay and the San Francisco Bay and Tampa Bay systems.

DISCUSSION

The two physical attributes giving the most insight into the type of circulation that exists in each system are the tidal prism (the volume of water added to the bay between low slack and high slack tides at the bay mouth) and average annual freshwater inflow volume. These attributes are convenient measures that are often used to represent tidal (mixing) and freshwater (stratification) influences, respectively. In situations where freshwater inflow dominates, conditions are favorable for formation of significant vertical density stratification with denser salty water on the bottom and less dense fresher water on the top. In conditions where tidal effects predominate, fresh and salt waters are well-mixed with little vertical variation of density. This distinction is important because the type of circulation likely to be found in an estuary is closely linked to its degree of stratification.

Harleman and Abraham (1966) combined tidal prism and average freshwater inflow into an "estuary number" that can be used as a general index of the degree of stratification in bays and estuaries. Using this technique, an estuary number of 100 is a dividing point with values greater than 100 indicating increasingly well-mixed conditions and values less than 100 indicating increasiungly stratified conditions. The stratification numbers for Sarasota, Tampa, and San Francisco Bays are about 1,000, 200, and 30, respectively.

For well-mixed conditions --such as those found in Tampa and Sarasota Bays-- tidally averaged horizontal circulation patterns predominate (Figure 2). These patterns are caused by the interaction of tidal water motion with the bottom configuration and general shape of the estuary. For stratified conditions --such as in San Francisco Bay-- horizontal patterns can still exist, with the added complication of a vertical circulation (Figure 2). The vertical pattern is caused by the tendency for freshwater to override the denser saltwater.

Little is known about the overall circulation pattern in Sarasota Bay. A few glimpses are available from the literature, however, that indicate existence of interesting circulation patterns. Fortune (1985, written communication) has reported on the paths of a series of drogues released in Sarasota Bay for a period of about 36 hours. Several drogues grounded in close proximity and others showed large net motion between tidal cycles. As part of a numerical modeling study of hurricane surge heights, Ross, Anderson, and Jerkins (1976) reported a nodal point in the central part of the bay.

In contrast, circulation in Tampa Bay has been the subject of several studies, including those by Ross and Anderson (1972), Ghioto (1973, written communication). Cote (1973, written communication), Ross (1973), and Goodwin (1977, 1980, and 1987). Results from many of these studies have shown numerically that tidally averaged water motion in Tampa Bay is comprised of a series of horizontal circulation features that are thought to control the overall movement and distribution of

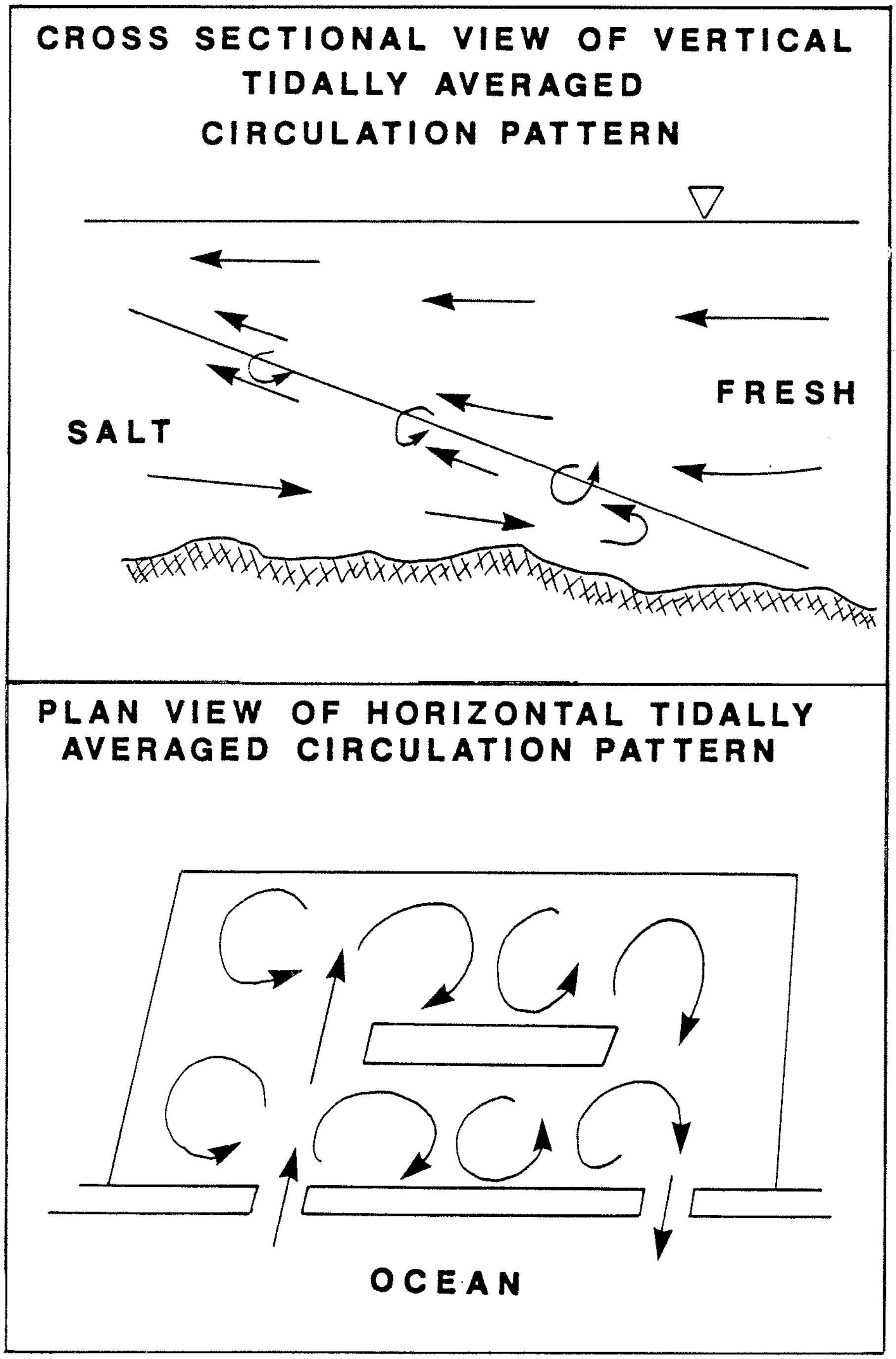

Figure 2. Vertical and horizontal tidally-averaged circulation patterns in estuaries.

dissolved and suspended material in the bay. The content of this paper is largely taken from the results of Goodwin (1987) and Goodwin (in press).

As previously mentioned, horizontal circulation is a tidally averaged water motion that is caused by interactions between incoming (flood) and outgoing (ebb) tidal flows and bay geometry. Figure 3, depicting tidal flood (3a), tidal ebb (3b), and tidally averaged (3c) water motion in a region at the mouth of Hillsborough Bay (see Figures 1 and 7), illustrates this phenomenon. A primary feature of the bay's geometry in this region is an east-west oriented ship channel with two dredge-material islands on the south side of the channel. The channel is about 25 feet deep, and the surrounding bay depths vary from 5 feet or less near the eastern shore to about 15 feet on the western edge of the illustrated area.

Visual comparison of the flood and ebb patterns of flow shows a large westward component in and along the ship channel during ebb that is not balanced by an equivalent eastward flow during flood. The fact that the channel lies to the north of the islands provides a path of little resistance to help convey ebb flows westward. No similar pattern forms during flood flow because the channel is then in the lee of the islands. Through an entire tidal cycle, the overall effect of the channel and islands is to produce a tidally averaged net or residual motion that is westward along the channel (Figure 3c). Because (in a net sense) the westward moving water must be replaced, circulation cells are set up to accomplish this and maintain continuity of mass throughout the affected region. This rather extreme example of geometry-controlled flow and circulation patterns is, nonetheless, a valid description of how horizontal circulation features are generated throughout Tampa Bay. This type of circulation has been called "tidal pumping" by Fischer, List, Imberger, and Brooks (1979).

Circulation features computed in Tampa Bay, using a simulation model having a grid size of 1,500 feet, are shown in Figure 4 for conditions as they existed in 1985. The 20 or so annotated circulation features indicate the complexity of the overall pattern of bay circulation that is believed to play a large role in the distribution and flushing of dissolved and suspended material. For comparison and a visual indication of the cumulative effects of dredge and fill activities, Figure 5 shows computed circulation patterns for 1880 conditions. Impacts of construction of ship channels, causeways, islands, and shoreline fills have been to both intensify and distort circulation features that existed prior to construction as well as to add new circulation features.

To compare circulation changes between 1880 and 1985, Goodwin (1987) plotted a measure of circulation intensity as a function of distance (Figure 6) and identified six zones from the Gulf of Mexico to the head of Hillsborough Bay having different circulation characteristics. Circulation zones are shown in Figures 4 and 5, and Table 2 gives the average circulation computed for each zone for 1880 and

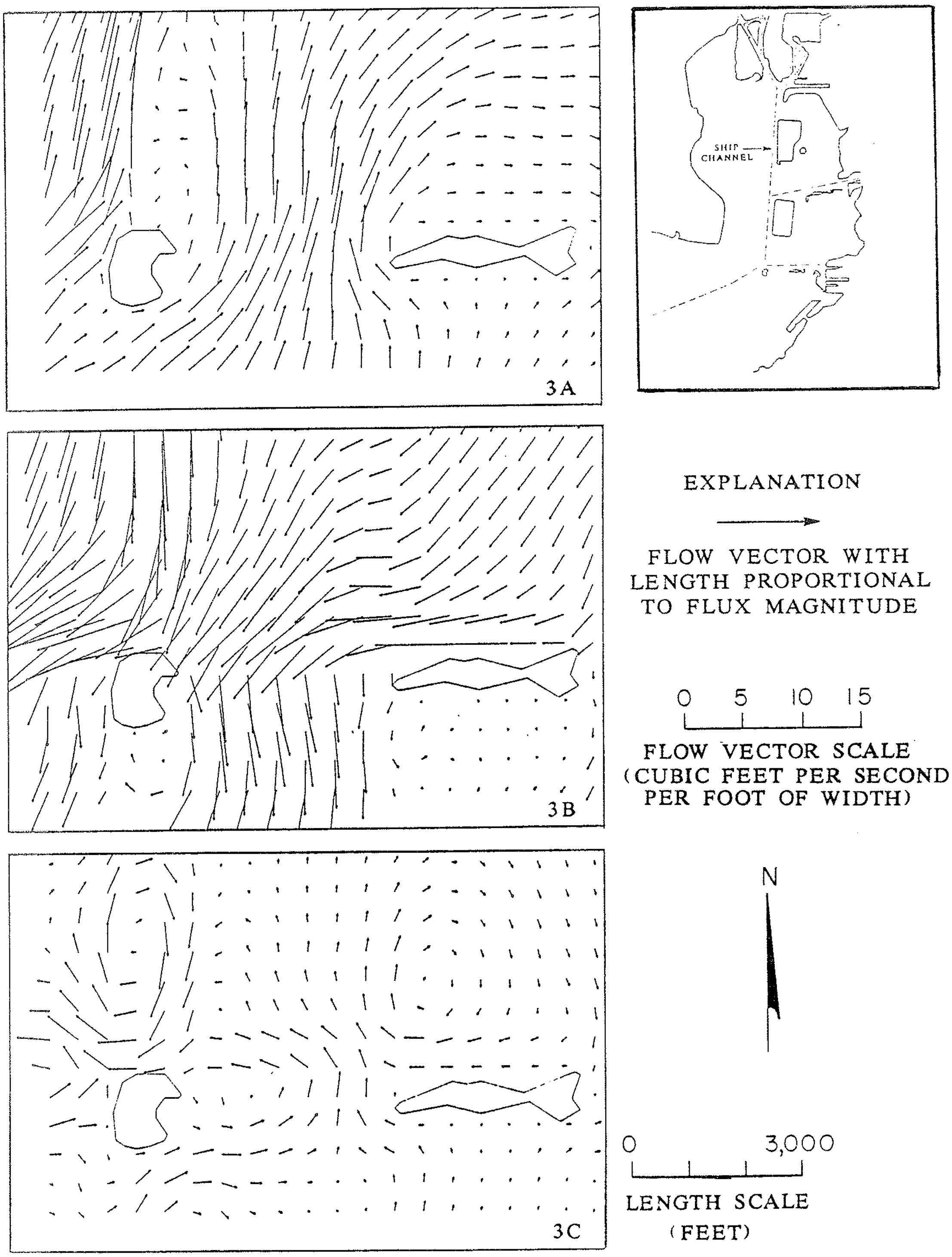

Figure 3. Flood (3A), ebb (3B), and tidally-averaged (3C) flow patterns in a region near the mouth of Hillsborough Bay.

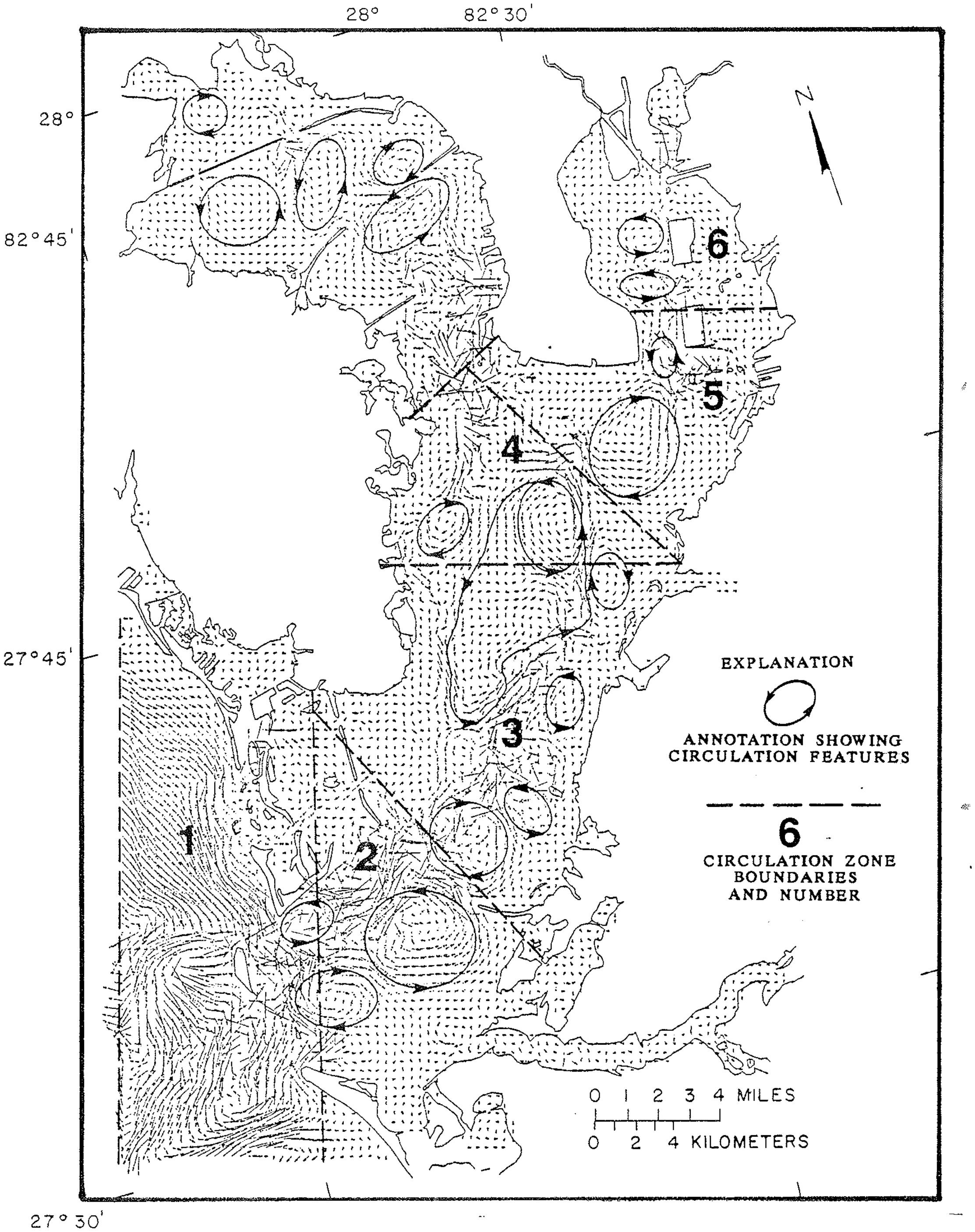

Figure 4. Tampa Bay tidally-averaged flow pattern in 1985 with computed circulation features and circulation zones.

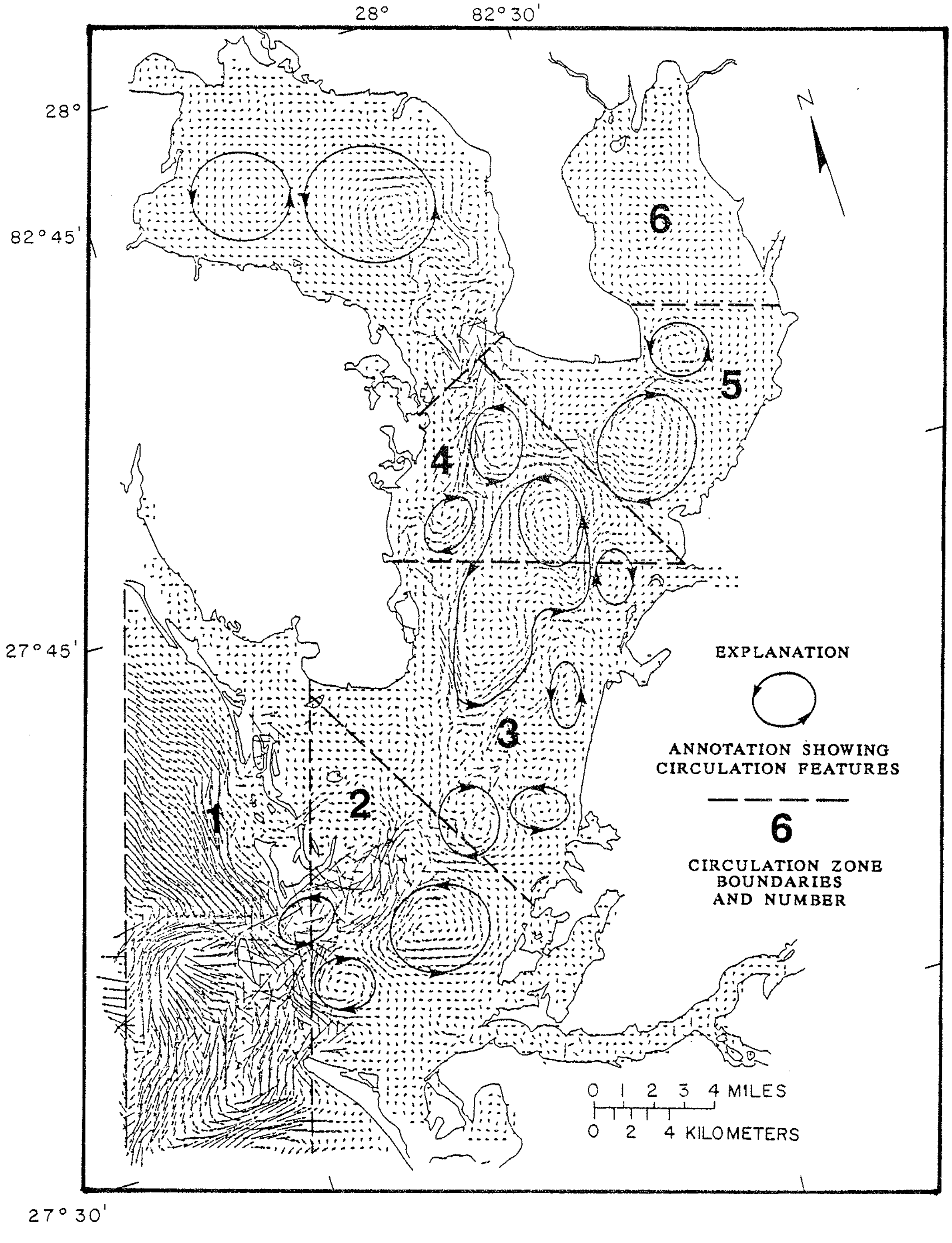

Figure 5. Tampa Bay tidally-averaged flow pattern in 1880 with computed circulation features and circulation zones.

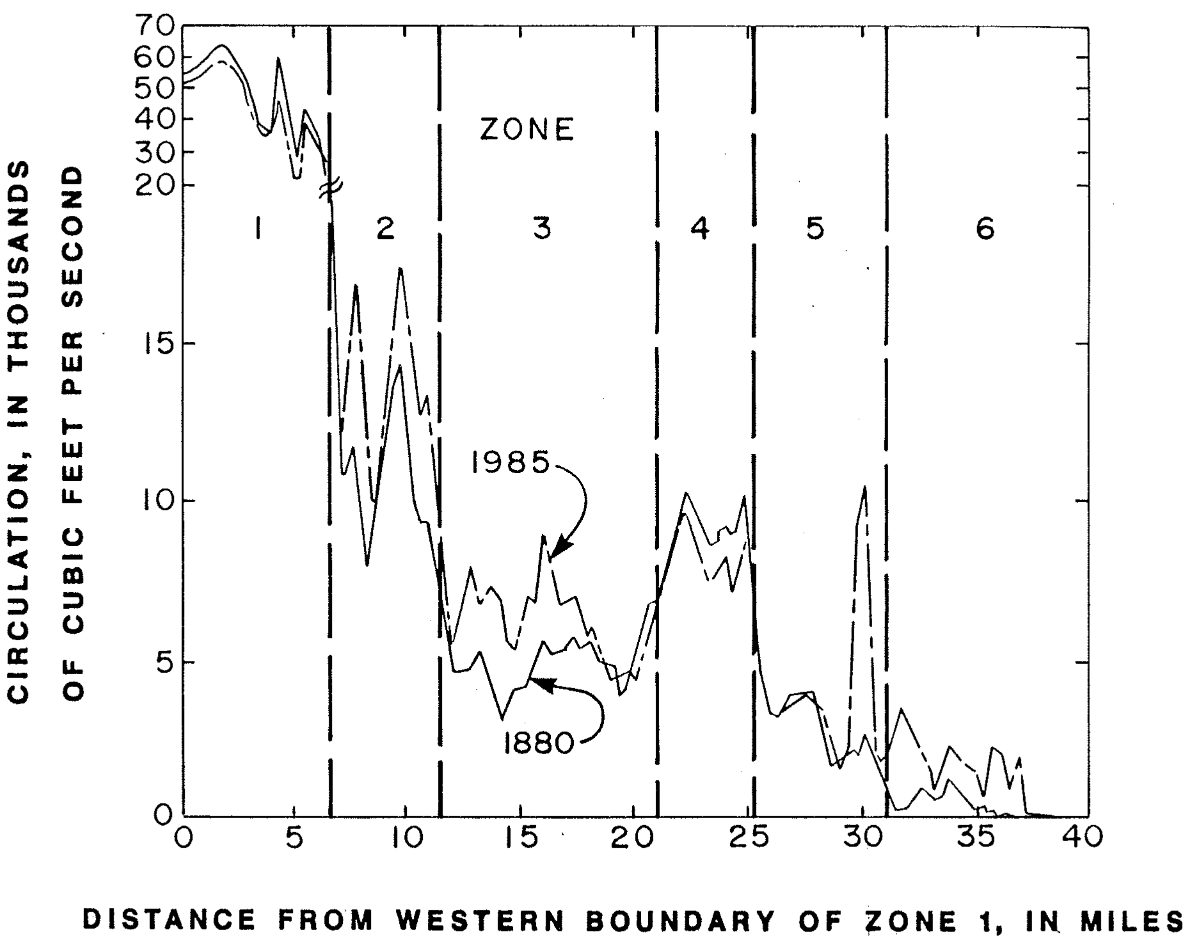

Figure 6. Comparison of computed circulation in Tampa Bay for 1880 and 1985.

1985 conditions, as well as the percentage change. In both 1880 and 1985, computed circulation in zone 3 is less than in either zone 2 or zone 4, although not as pronounced as 1985. It is not known whether the circulation minimum in zone 3 influences the overall rate of constituent flushing from Tampa Bay to the Gulf of Mexico. Circulation differences range from a decrease of about 10 percent in zone 1 at the mouth of the bay to an increase of 275 percent in Hillsborough Bay (zone 6). The large computed increase in Hillsborough Bay circulation was investigated in more detail by Goodwin (in press) using a 500-ft grid model having nine times more spatial resolution than the Tampa Bay model. This model assumes no difference between 1880 and 1985 freshwater inflow. It does, however, include a total bay volume increase of about 10 percent and a tidal prism decrease of 6 percent during the same period.

Table 2. Circulation changes in Tampa Bay between 1880 and 1985 by zone.

Zone	Circulation in cubic feet per second 1880	1985	Percent Change
1	45,500	41,100	- 9.7
2	10,400	13,400	+28.8
3	4,900	6,300	+28.6
4	8,600	7,800	- 9.3
5	2,700	3,700	+37.0
6	400	1,500	+275.0

The smaller grid model confirmed that dredge and fill construction of channels, islands, and shoreline fills between 1880 (Figure 7a) and 1985 (Figure 7b) caused a dramatic increase in the number and intensity of circulation features in Hillsborough Bay (Figure 8). A comparison plot of circulation versus distance from the mouth of Hillsborough Bay (Figure 9) also demonstrates large circulation increases in most parts of the bay between 1880 and 1985.

In addition to obvious circulation dissimilarities, the 500-foot grid model also revealed what is believed to be an important similarity in the Hillsborough Bay circulation patterns of 1880 and 1985. There is a tendency for tidally averaged water motion to flow in a seaward direction along the shallow bay margins and in a landward direction in the deeper central part of the bay. Although unconfirmed by direct flow measurements, this computed pattern is at least partially substantiated

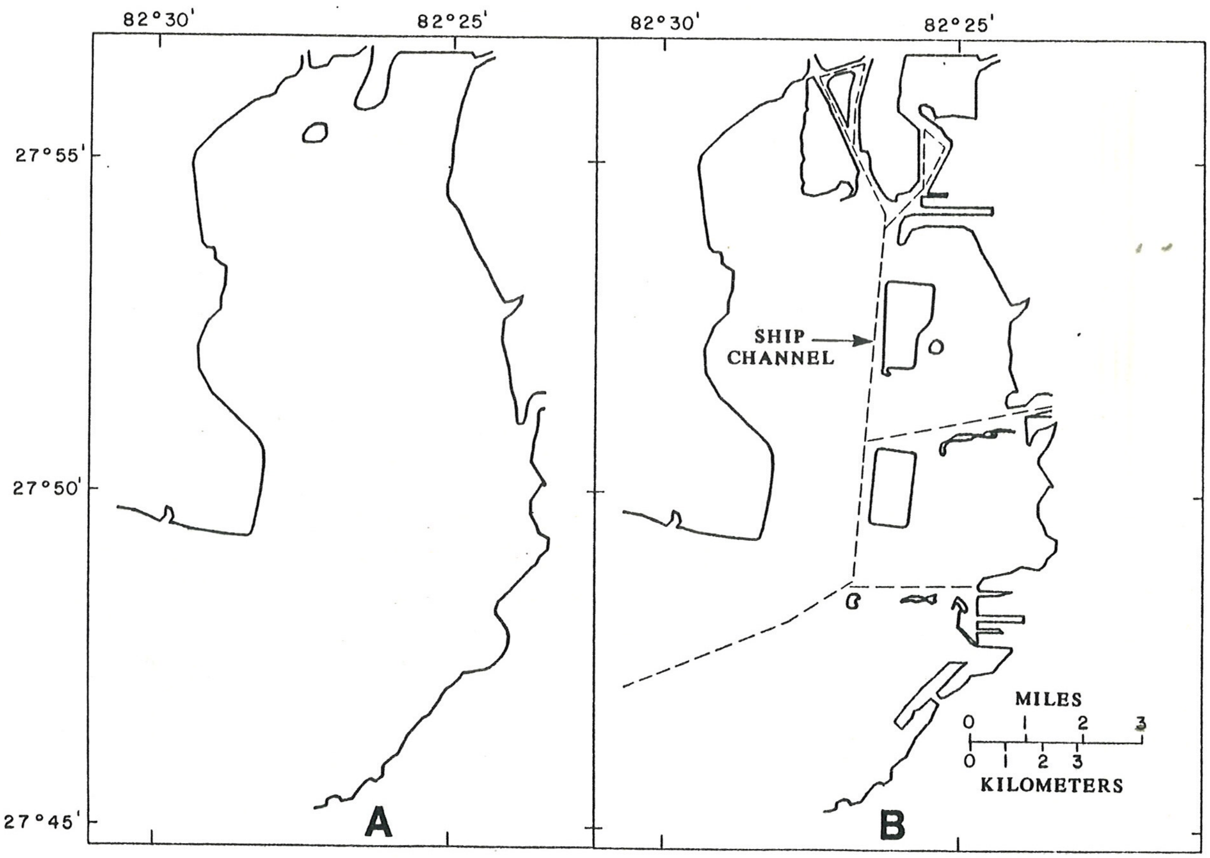

Figure 7. Shorelines of Hillsborough Bay in 1880 (A) and 1985 (B).

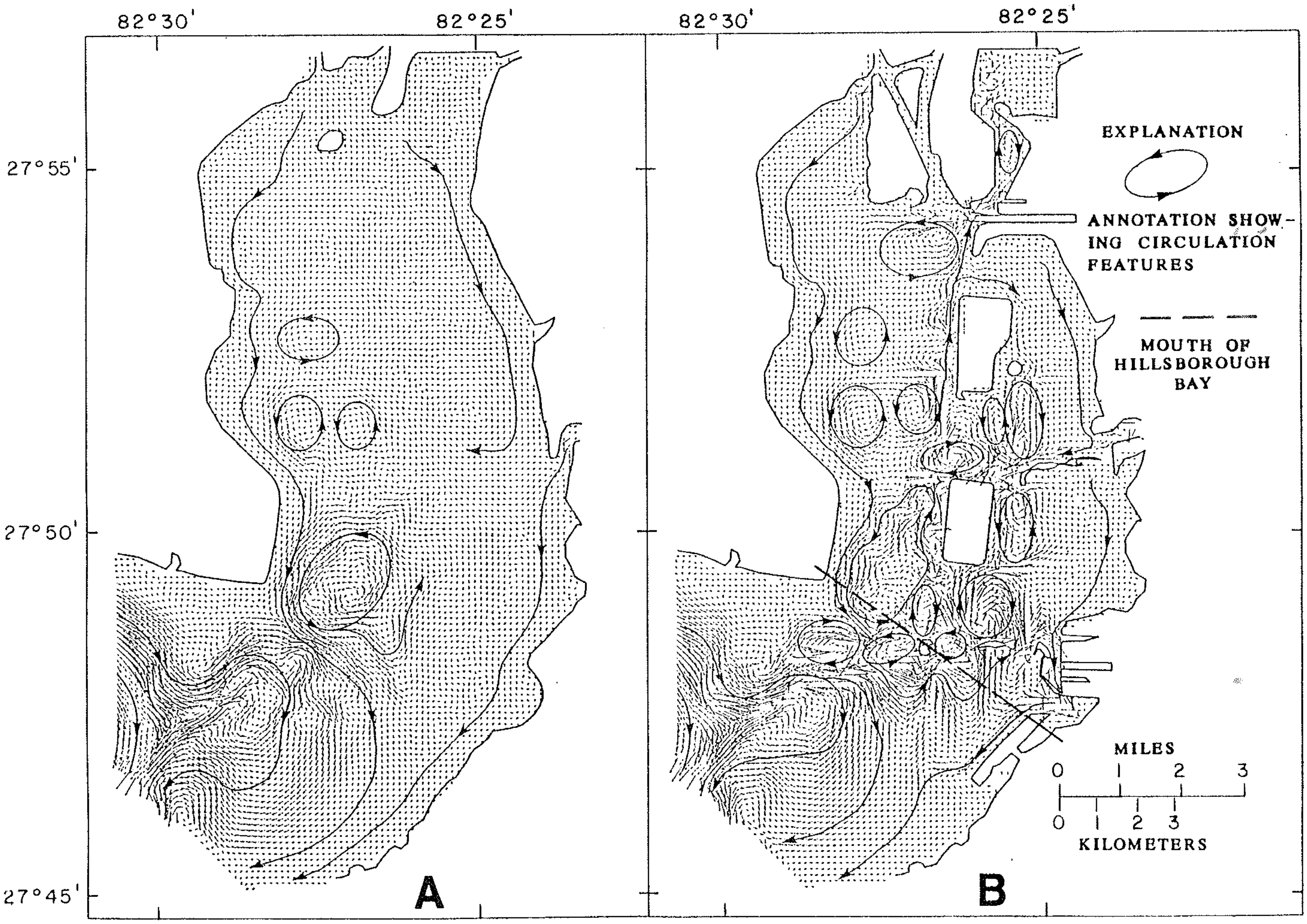

Figure 8. Tidally-averaged flow pattern with computed circulation features in Hillsborough Bay in 1880 (A) and 1985 (B).

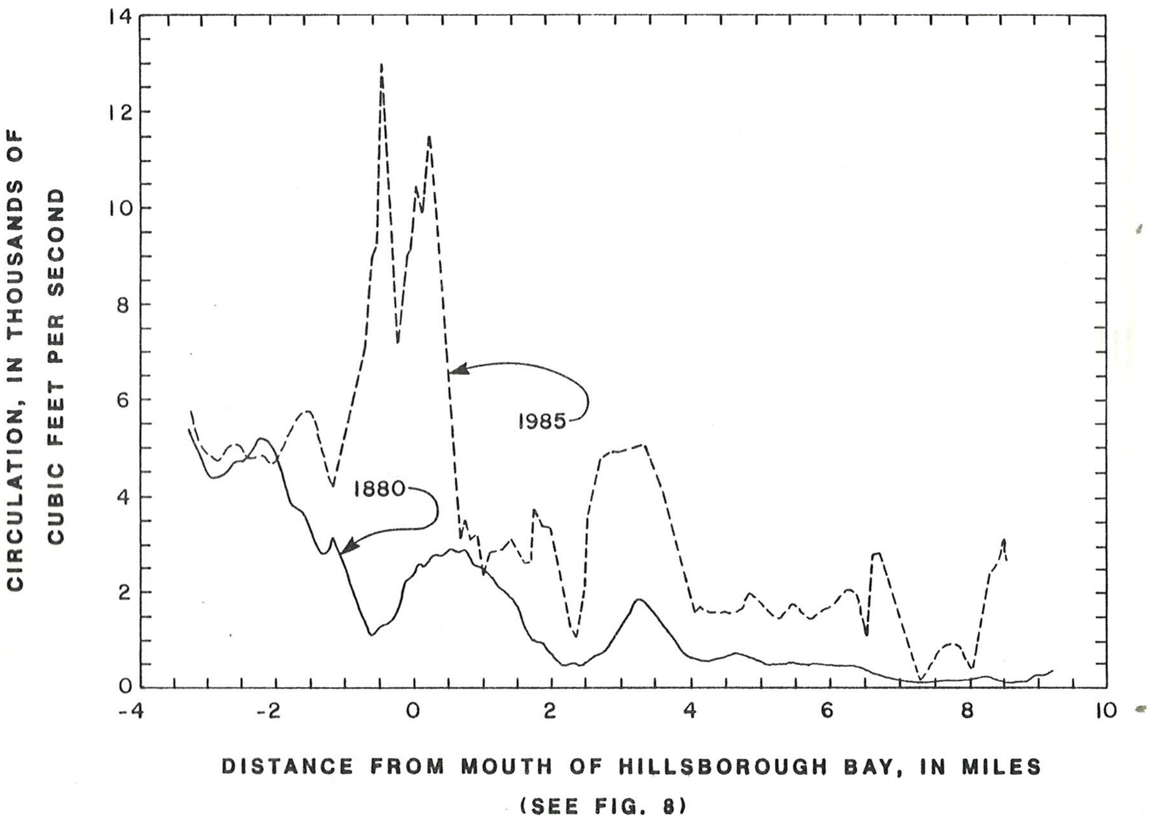

Figure 9. Comparison of computed circulation in Hillsborough Bay for 1880 and 1985.

by the 12-year average salinity distribution of Hillsborough Bay (Figure 10).

Assuming that this generalized, tidally averaged flow concept is correct, Goodwin (in press) estimated how circulation increases between 1880 and 1985 may have changed the average time needed for suspensed or dissolved material to transit from the head to the mouth of Hillsborough Bay. The transit time in 1880 is estimated to have been about 60 days. Due to increased circulation, the transit time in 1985 is estimated to have been about 30 days. This indicates that Hillsborough Bay may now be able to flush itself of waterborne material having a landward source in about half the time that it took in 1880.

It is likely that increased flushing has also caused an increase in bay salinity because tributary freshwater inflow to Hillsborough Bay can also be conveyed through the bay in about half the time that it took in 1880. The salinity increase in the bay from 1880 to 1985 due to increased flushing is computed to be in the range of 2 to 3 parts per thousand. Reductions in Hillsborough River discharge (Flannery, this report) probably have also contributed to an increase in bay salinity, but this effect has not been quantified.

In spite of the circulation information available for the Tampa Bay system, much more remains unknown. Questions regarding the effects of wind are unanswered for both Tampa and Sarasota Bays. Are wind effects dominant or do they represent short-term perturbations on the tide-induced circulation? Another unanswered, circulation-related question that has a large bearing on overall flushing rates and the concentration of waterborne constituents is the mechanism of exchange between bay and gulf waters. Of the water exiting Tampa and Sarasota Bays during ebb tide, what percentage returns during the next flood tide? These and other Tampa Bay questions are addressed in a comprehensive management plan, as requested in Florida's Surface Water Improvement and Management Act of 1987. Similar answers are being sought for Sarasota Bay through a federally sponsored estuarine initiative administered by the U.S. Environmental Protection Agency.

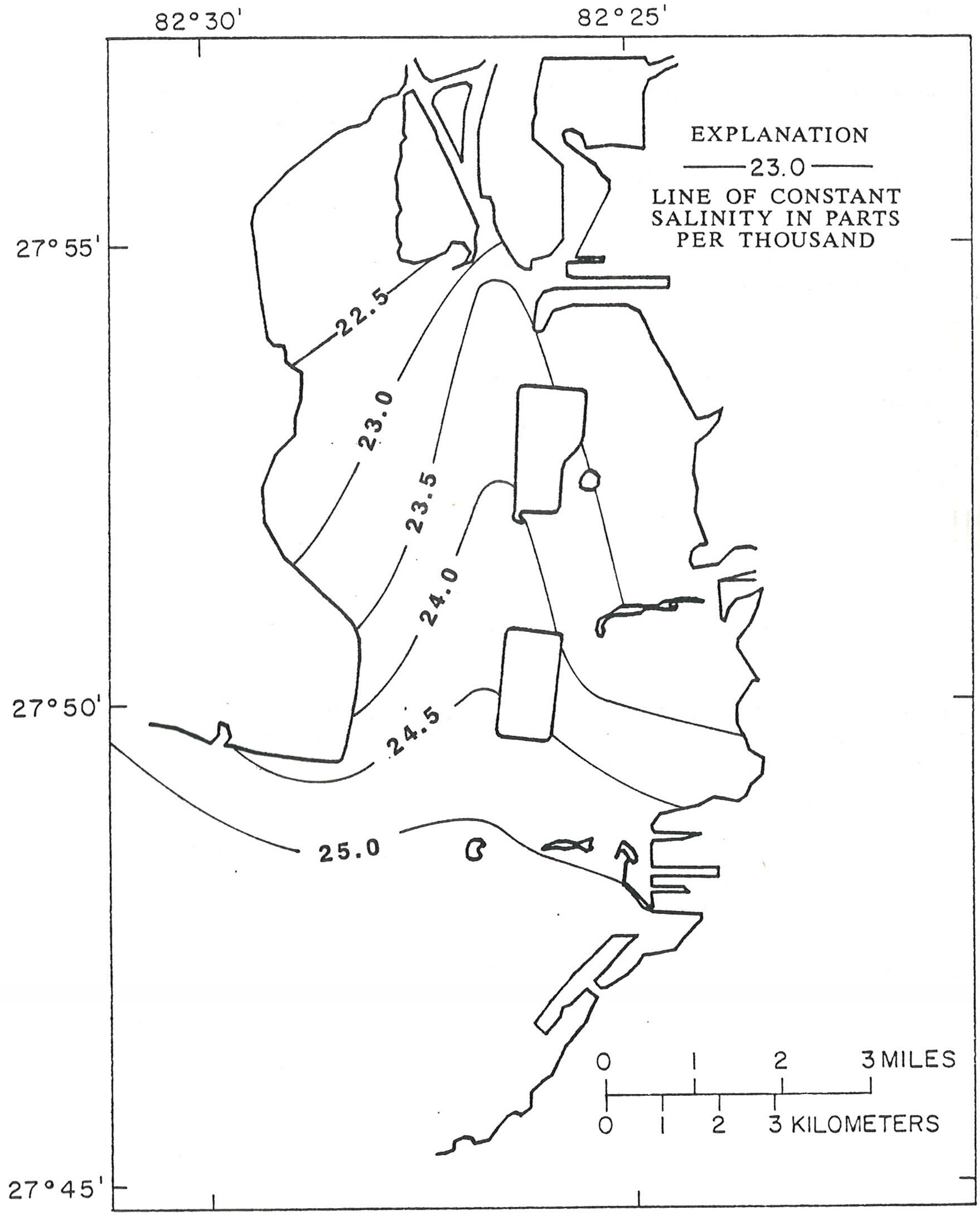

Figure 10. Distribution of average salinity in Hillsborough Bay computed from 12 years of monthly observations.

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WATER QUALITY TRENDS AND ISSUES, EMPHASIZING TAMPA BAY

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INTRODUCTION

Modern reports of water quality in Tampa Bay go back 150 years, in the form of accounts of red tides, fish kills due to freezes, and mass mortalities of bay life caused by heavy rains and runoff. Even earlier records of water quality may be read in the shell middens created by prehistoric humans, by the seasonality of deposits, identity and size of shelled animals, or their microscopic or chemical structure. In this paper, I shall review a much more recent collection of facts about Tampa and Sarasota Bays, actually just more than one decade's worth, to fulfill NOAA's request that readers might learn (from existing information) something about overall water quality in the bays, and ongoing or new issues or management programs related thereto.

The water quality of Tampa and Sarasota Bays is rather well-known but poorly understood because the underlying chemistry and biology which control water quality have received scant attention. Water quality refers to measurable comparisons to specific standards or designated uses, and in a more general way includes parameters associated with violations or loss of use, although their direct, mechanistic link to an impact is unclear. For example, Florida has no specific standard for nitrogen and excess nitrogen does not impair human contact or use, _per se_, but nitrogen's known origin in effluent and runoff and role as a stimulant of phytoplankton blooms cause it to be monitored as an indicator of water quality.

The statement that local water quality is well known is true in the following senses but with certain qualifications. Compared to other estuaries of the nation, Tampa Bay's continuous monitoring program is relatively mature (16 years). The program covers the entire bay and tributaries, although very shallow areas are probably under-represented. Quality control has been above average although a change in analytical technique for nitrogen prevents meaningful trend analyses. There is also a feeling among bay area scientists and resource managers that the very large data base is not being utilized fully to understand processes controlling water quality, such as weather, runoff, circulation, and biological interactions.

Nevertheless, the general water quality monitoring program in Tampa Bay is a facet of resource management deserving national attention. The program was begun in 1972 by the Hillsborough County Environmental Protection Commission (HCEPC) and covers all of Tampa Bay, even the waters of Pinellas and Manatee Counties (which have not assisted HCEPC with monitoring expenses). The program entails monthly sampling at 54 bay and 12 tidal tributary stations, with in situ measurements and water samples taken near the surface, middle, and bottom of the water column. Twenty-eight parameters are measured. Results are reported every two years in graphic and text form. More than 388,000 data are available for trend analysis of parameter-specific and "general" water quality of the bay, and another two-year report for 1986-87 is in press.

Comparison to Other Systems

In their Tampa BASIS review of nutrients, Fanning and Bell (1985) stated, "Compared to other estuaries and coastal waters, Tampa Bay is considerably enriched in phosphate. In fact, no other major estuarine or coastal area we know of even comes close to having as high a phosphate concentration". The Alafia River has been the primary source of phosphate because it [and neighboring rivers] drain the lands east of the bay which are underlain by a phosphate-rich "Bone Valley" Formation. Industrial discharges elevated phosphate levels in the river and bay for decades but these levels are declining as water conservation and discharge limits are enforced. The same geology and industrial processing have caused relatively high levels of radionuclides in the upper bay (Fanning, Breland and Byrne 1982).

GENERAL WATER QUALITY

Standards and Beneficial Uses

Waters of Tampa and Sarasota Bays are classified by the State of Florida as Class II or III, which provide for shellfish propagation or harvesting and maintenance of fish and wildlife, respectively. Both categories recognize body contact with bay water as a safe use (Table 1). Actual taking of shellfish is limited to smaller parts of Class II waters because of contamination from runoff, and sewage treatment plants. Despite such contamination, most of the two bays are also classified as "Outstanding Florida Waters", which is supposed to prevent degradation of existing water quality by applying more stringent conditions on state discharge and dredge-fill permits. Except for Sarasota Bay, all outstanding waters are also state aquatic preserves. The preserves are managed to perpetuate their ecological, recreational, or scenic qualities.

Bay-wide Assessments

The State of Florida made a recent assessment of Tampa Bay's water quality (Palmer and McClelland 1988) and concluded that "overall water quality in Tampa Bay is improving. Furthermore, the long-term averages indicate that the water quality throughout the bay is fairly good. However, water quality standards violations do occur in all of the major bay segments with Hillsborough Bay and Old Tampa Bay generally exhibiting the worst problems." Another, earlier assessment by the State of water quality throughout Florida (Hand, Tauxe and Watts 1986) determined whether Tampa and Sarasota Bays were meeting their designated uses (Figure 1). That report identified poor water quality in Hillsborough Bay and its tributaries, eutrophication problems caused by STP effluent in Old Tampa Bay, and good water quality in the Little Manatee and Manatee Rivers, and Lower Tampa Bay. Sarasota Bay was found to have fair to good water quality. [Note: the Florida DER is producing a 1988 biennial report to EPA with more current findings; the 305(b) Report will be available late in 1988].

Table 1. Water quality classifications and designated uses of Tampa and Sarasota Bays.

	Class	Aquatic Preserves	OFW*	Shellfish
Old Tampa Bay	II	Pinellas	West Side	Closed
Hillsborough Bay	III	None	None	Closed
Tampa Bay	II, III	3 Preserves	3 Preserves	Mixed
Boca Ciega Bay	II	All	All	Closed
Sarasota Bay	II, III	None	All**	Mixed

* Outstanding Florida waters
** Except creek mouths

Data from the HCEPC monitoring program have been used for years to develop bay-wise water quality assessments (Boler 1986). The HCEPC employs a "general water quality index" comprised of dissolved oxygen, chlorophyll a, total coliform, biochemical oxygen demand, total phosphorus, total Kjeldahl nitrogen,and effective light penetration data. A scale is used to generate points for each parameter and points are weighted and summed to produce the water quality index. The index is computed for each station and values between stations are interpolated for graphic presentation.

General water quality is highest in the lower bay and poorest in Hillsborough Bay (Figure 2). Water quality is best in the dry season and worst in the wet season (Figure 3). There has been a general improvement in water quality throughout the bay since 1975, even when years of relatively low rainfall are considered (Figure 4). Improvements in Hillsborough Bay are attributed to the City of Tampa's advanced waste treatment plant, and are believed responsible for the colonization of shallows along the Interbay Peninsula by seagrasses and rhizophytic macroalgae (City of Tampa 1988).

Overall, Lewis and Estevez (in press) concluded that Tampa Bay is not grossly polluted, certainly not beyond the point of rehabilitation; that parts of the bay had better water quality than others, for natural and cultural reasons; and that some pollutants are declining while others are increasing.

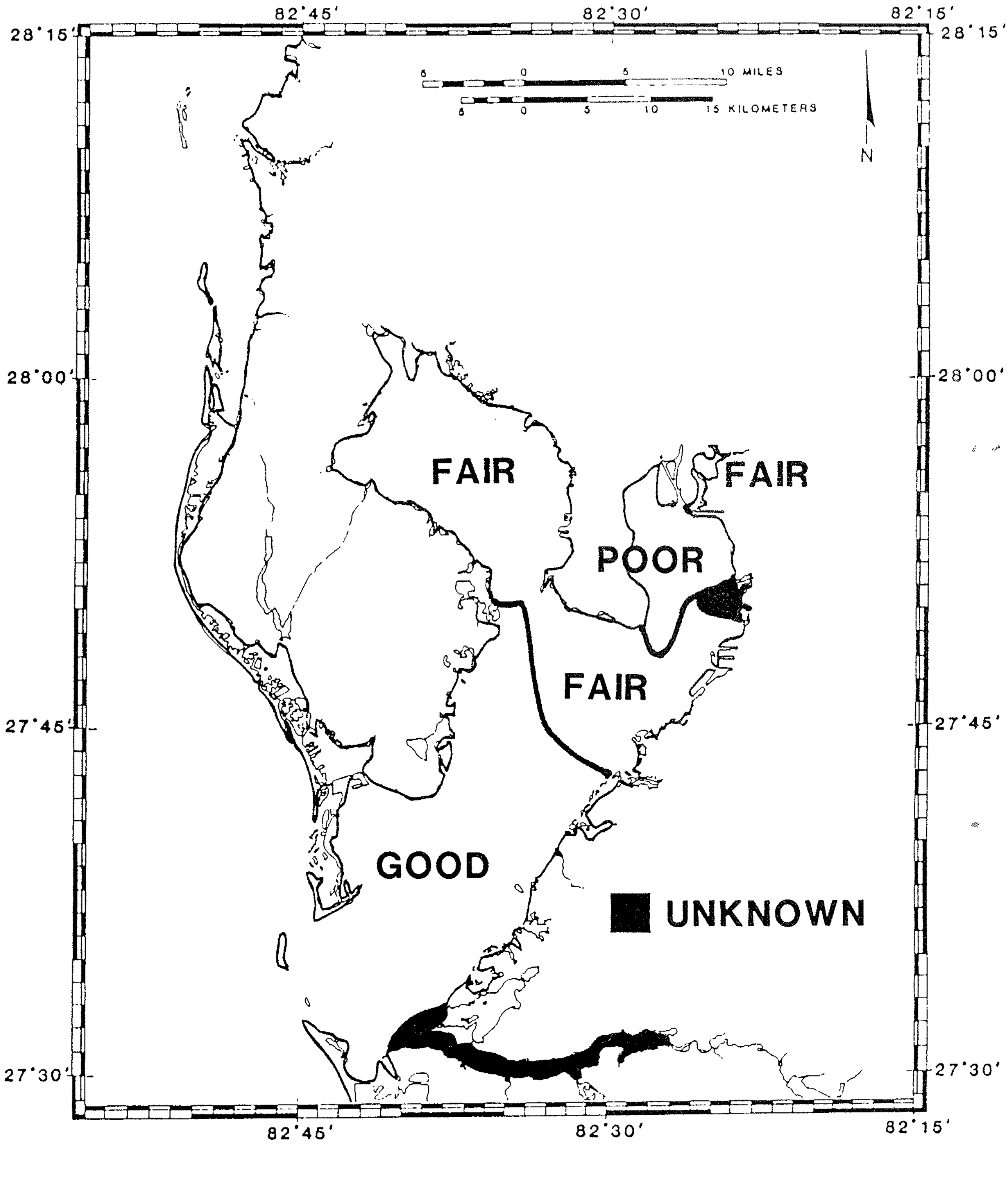

Figure 1. Tampa Bay water quality. Good water meets designated uses; use of fair water is partially met. Poor water does not meet designated use (Hand et al. 1986).

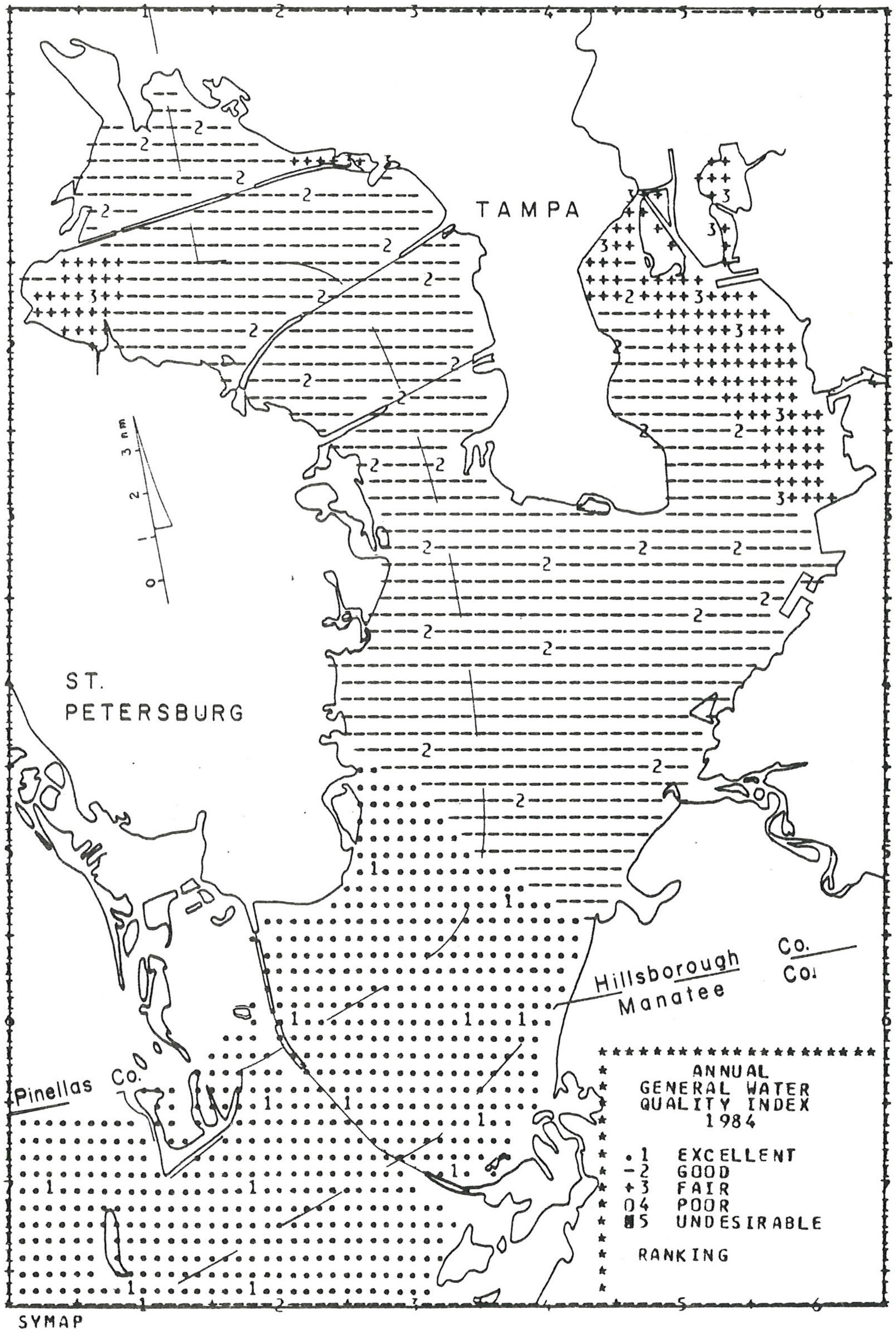

Figure 2. General water quality index, 1984 (Boler 1986).

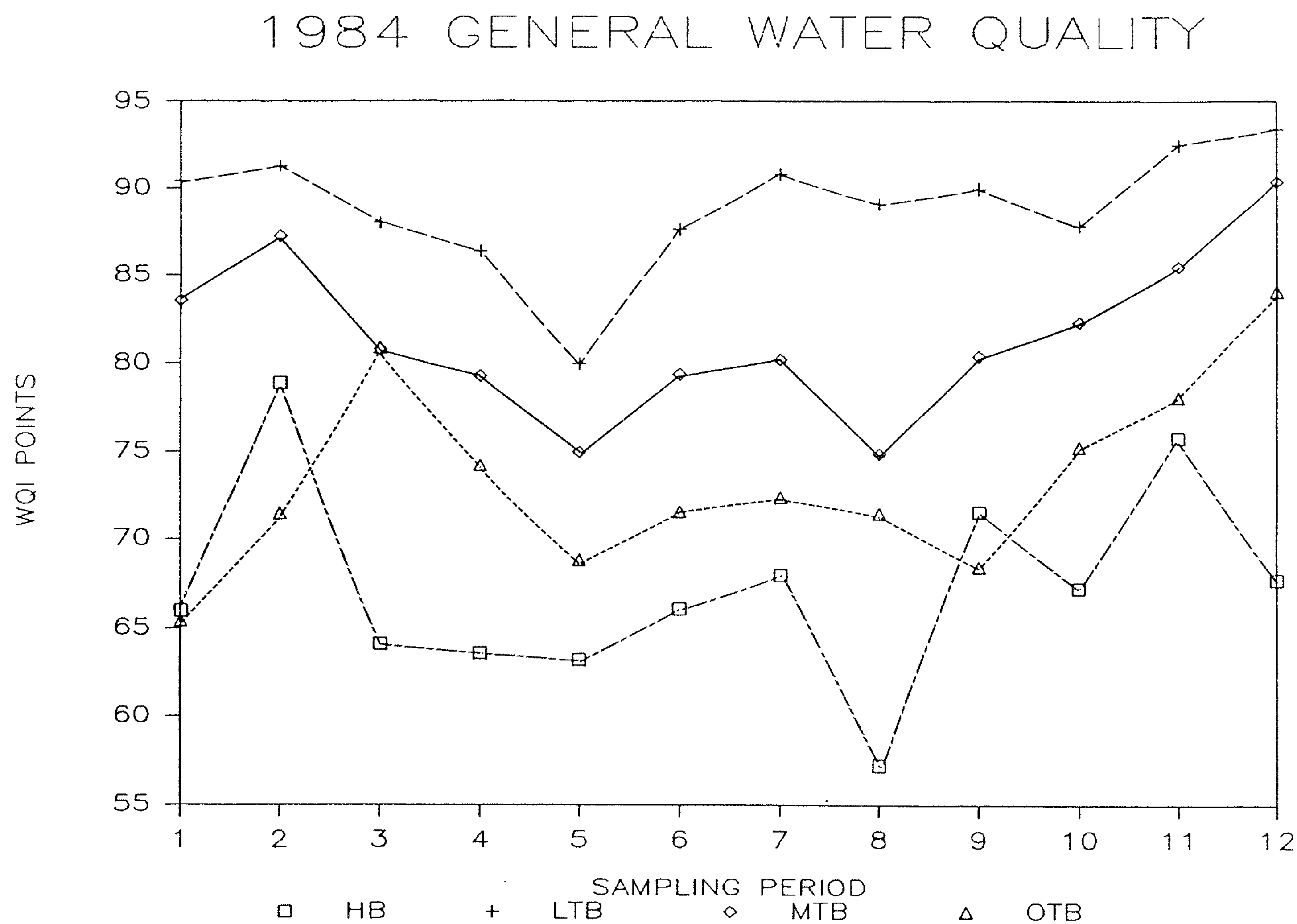

Figure 3. Seasonal variation in water quality in Hillsborough Bay (HB); Lower Tampa Bay (LTB); Middle Tampa Bay (MTB) and Old Tampa Bay (OTB), from Boler (1986).

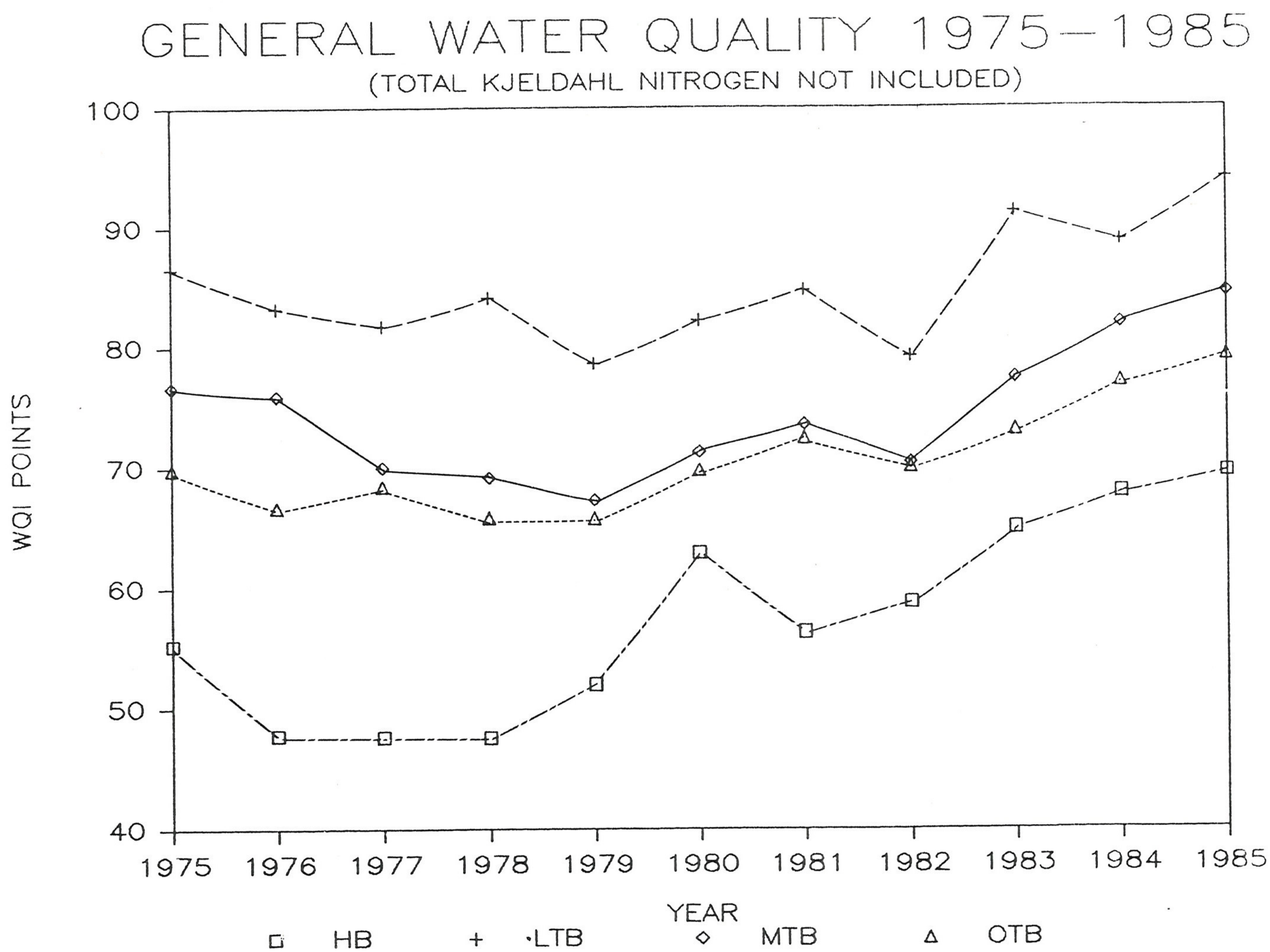

Figure 4. Annual trends in general water quality (Boler 1986).

PARAMETERS OF INTEREST

Reports by the HCEPC allow the depiction of spatial and temporal patterns useful in comprehending the bay's overall character, and relationship to other estuaries. Most of the following discussion is adapted from Boler (1986) for 1984 or 1985. Rainfall in 1984 was below average (32.3 inches) compared to 1985 (44.6 inches).

Salinity

Salinity ranges from nearly zero in tidal rivers to normal salinity of the Gulf of Mexico. Salinity less than 50 percent occurs in Old Tampa and Hillsborough Bays, and the tidal rivers. Runoff affects the upper bays more than the lower bay (Figure 5). The mid-bay area usually exhibits the greatest transitional salinities.

Light

The color, nutrient-enhanced plankton, and detritus associated with runoff reduce light penetration in approximately the same areas and times of salinity reduction (Figure 6). Seasonal variation in light climate is much more complicated than salinity, however, owing to the non-conservative nature of some light-controlling factors. Since 1974, mean Secchi depth for Lower Tampa Bay has exceeded 70 inches, where seagrasses are most abundant, whereas the middle bay area has had some years with less than 70 inches of effective light penetration. Upper bay areas have had the poorest light climate, especially Hillsborough Bay (Figure 7).

Chlorophyll

Chlorophyll *a* levels between 10.0-15.0 ug/l are common throughout much of Tampa Bay inland of the Sunshine Skyway Bridge, and chlorophyll concentrations greater than 20 ug/l are common in Hillsborough Bay (Figure 8). A slight increase in chlorophyll may be occurring through time over several bay areas although levels in Hillsborough Bay appear to be declining (Figure 9). In developing a water quality model for Hillsborough Bay, Ross, Ross and Jerkins (1984) included a self-shading factor to account for the inhibition of photosynthesis by very high concentrations of phytoplankton in surface waters, as reflected by chlorophyll level.

Nutrients

The exceptional levels of total phosphorus (TP) in Tampa Bay were introduced in an earlier section. In 1984, TP ranged from 1.55 mg/l as P in Hillsborough Bay (at the Alafia River) to 0.08 mg/l at Egmont Key (Figure 10). Phosphorus levels have been declining for more than a decade (Figure 11) owing to environmental regulations and production

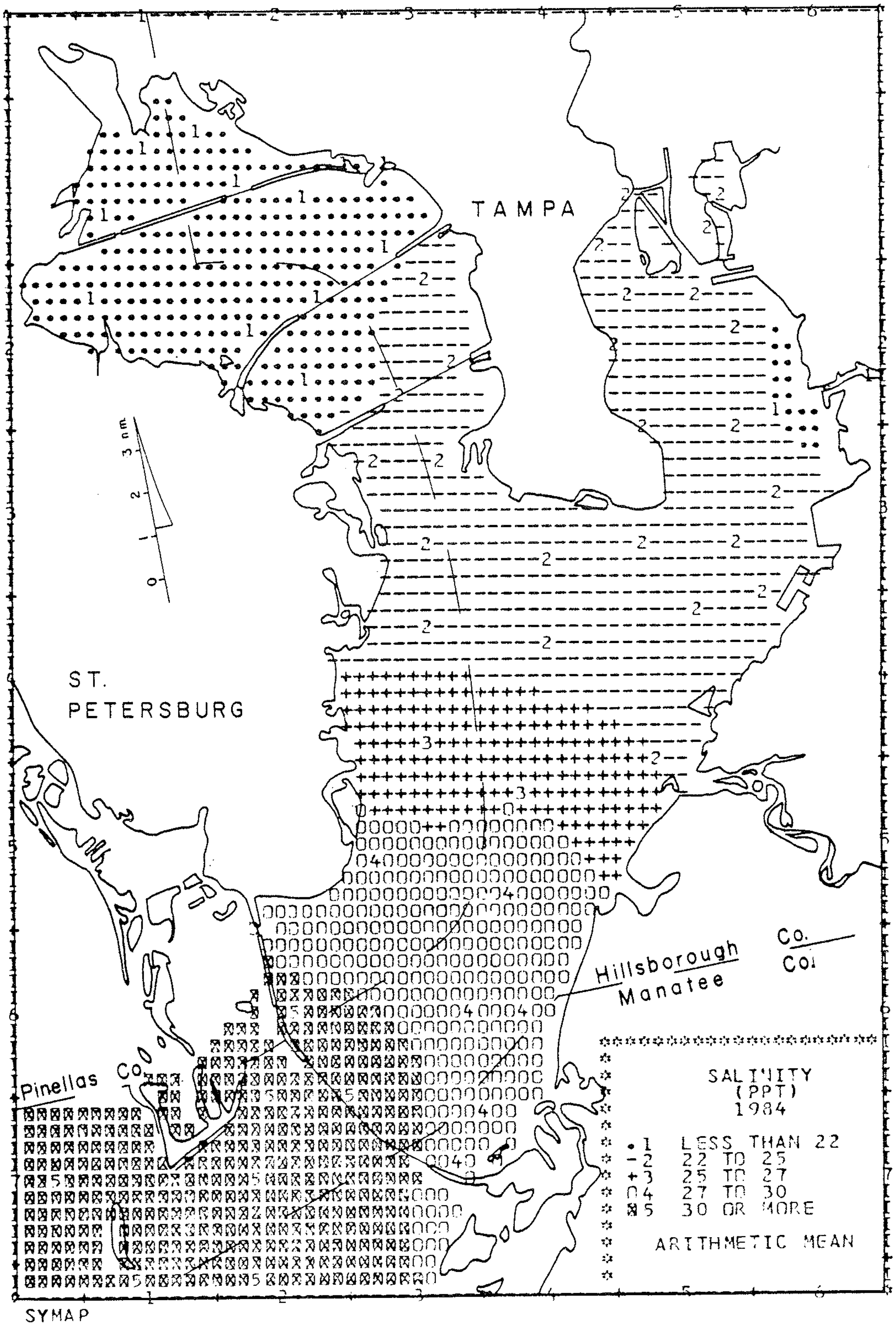

Figure 5. Mean annual salinity, 1984 (Boler 1986).

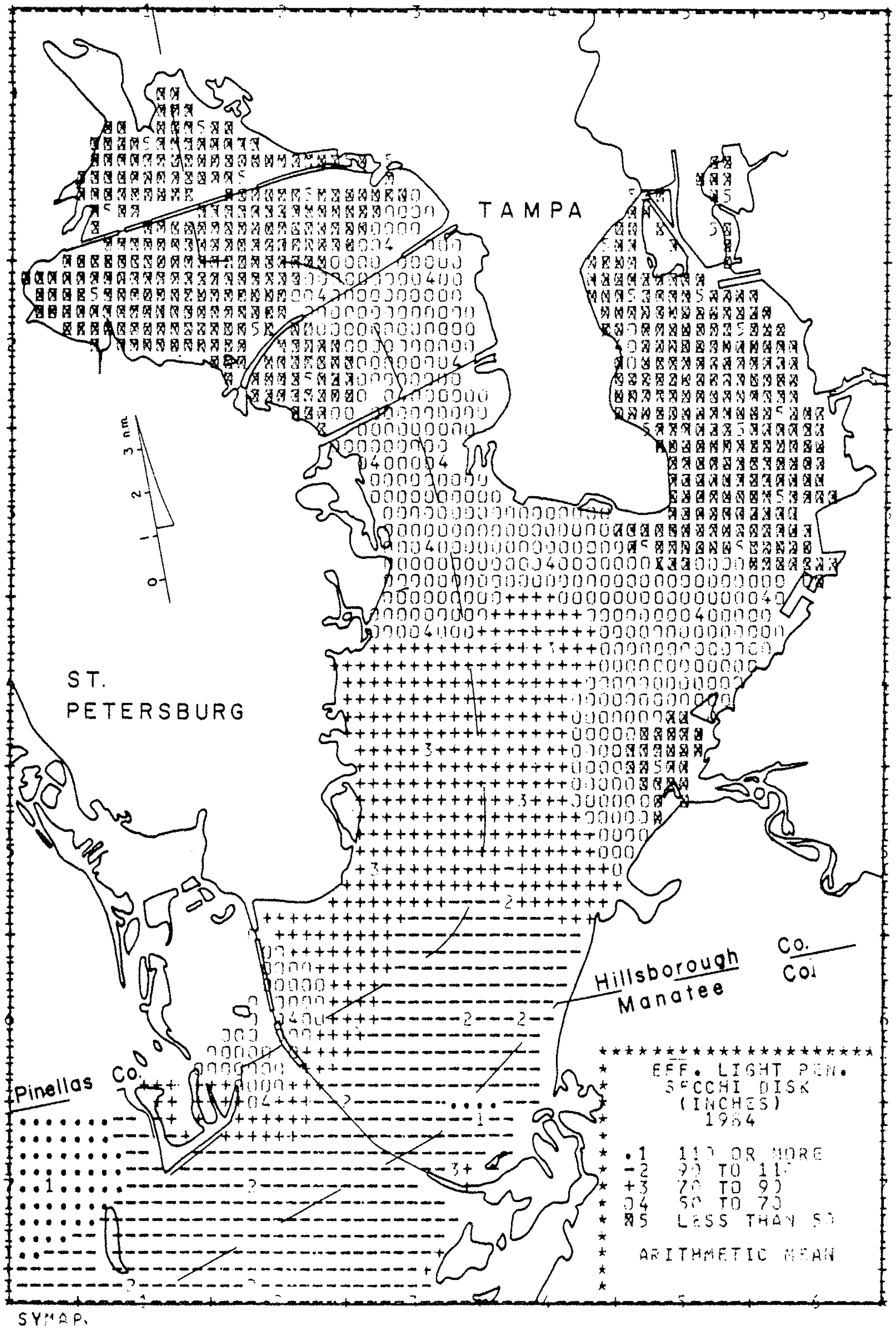

Figure 6. Mean annual Secchi disk penetration, 1984 (Boler 1986).

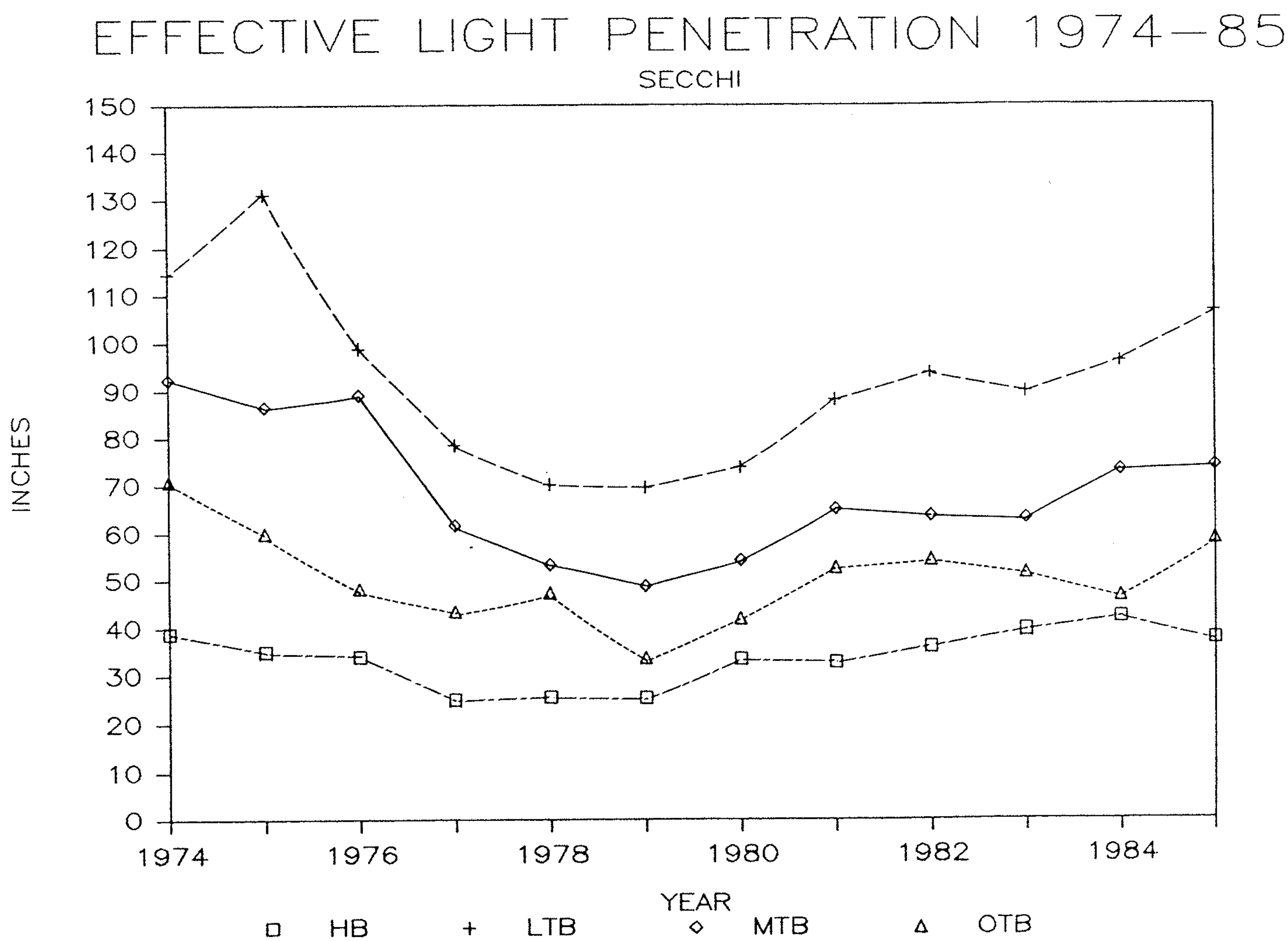

Figure 7. Annual trends in effective light penetration (Boler 1986).

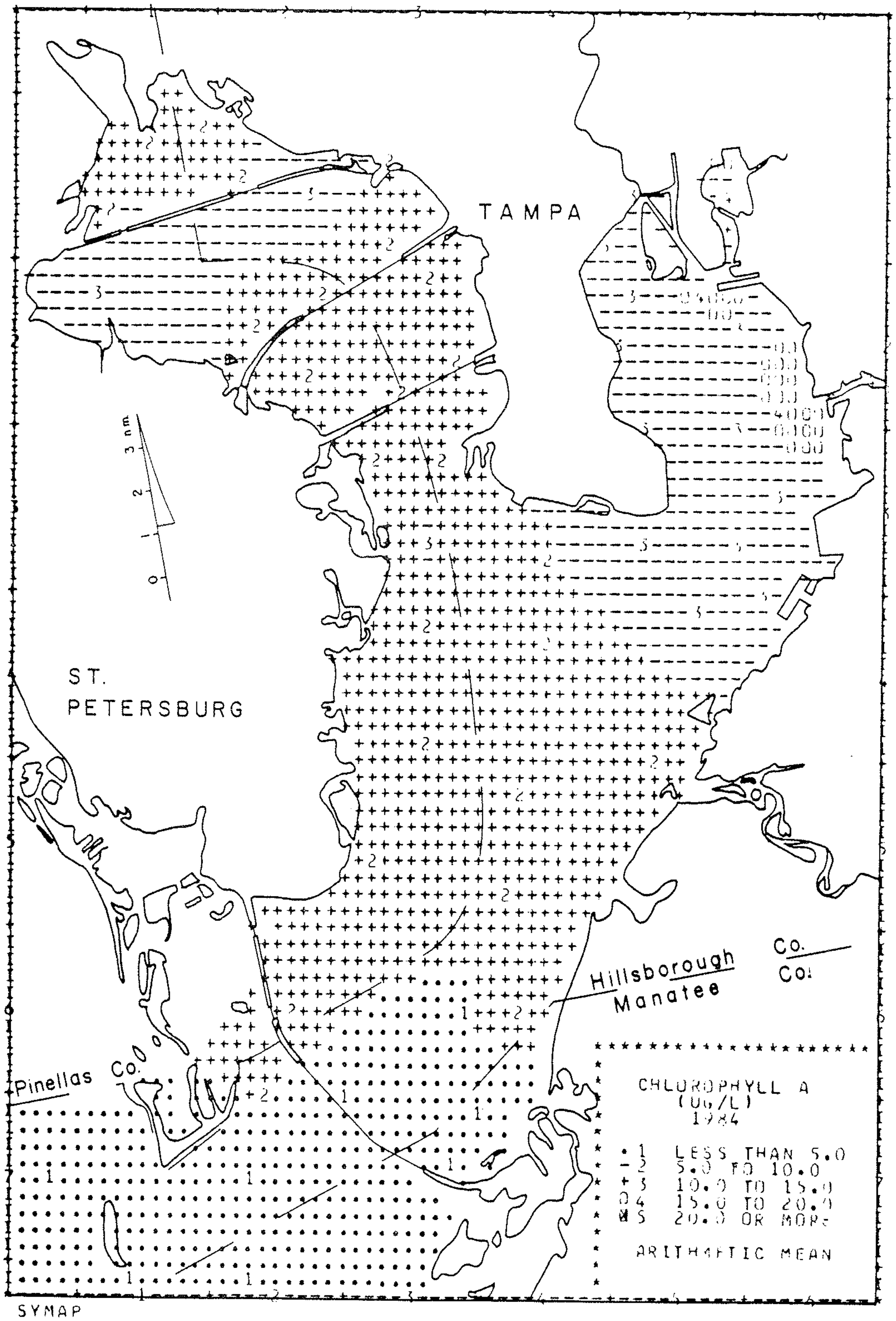

Figure 8. Mean annual chlorophyll a, 1984 (Boler 1986).

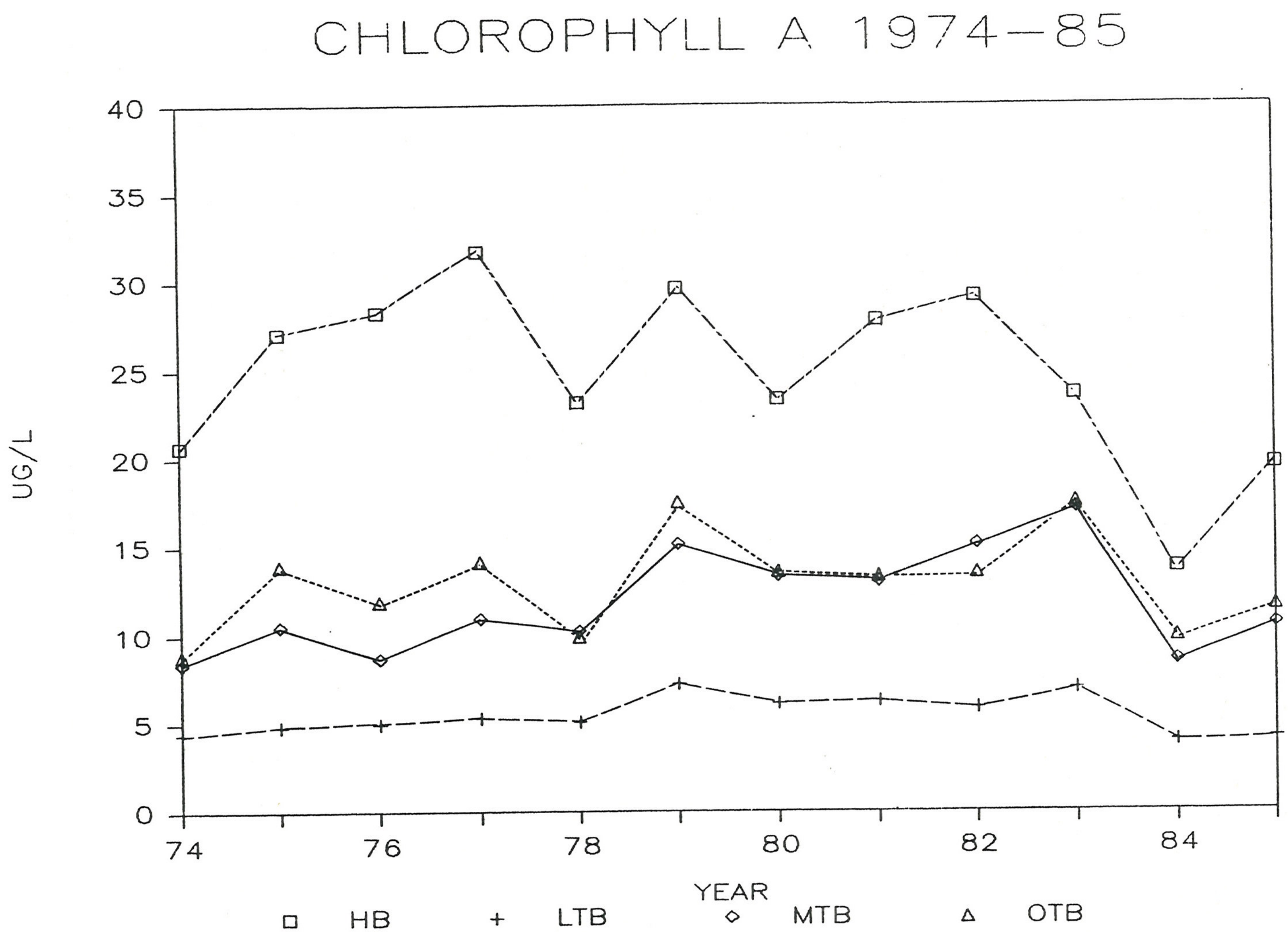

Figure 9. Annual trends in chlorophyll a (Boler 1986).

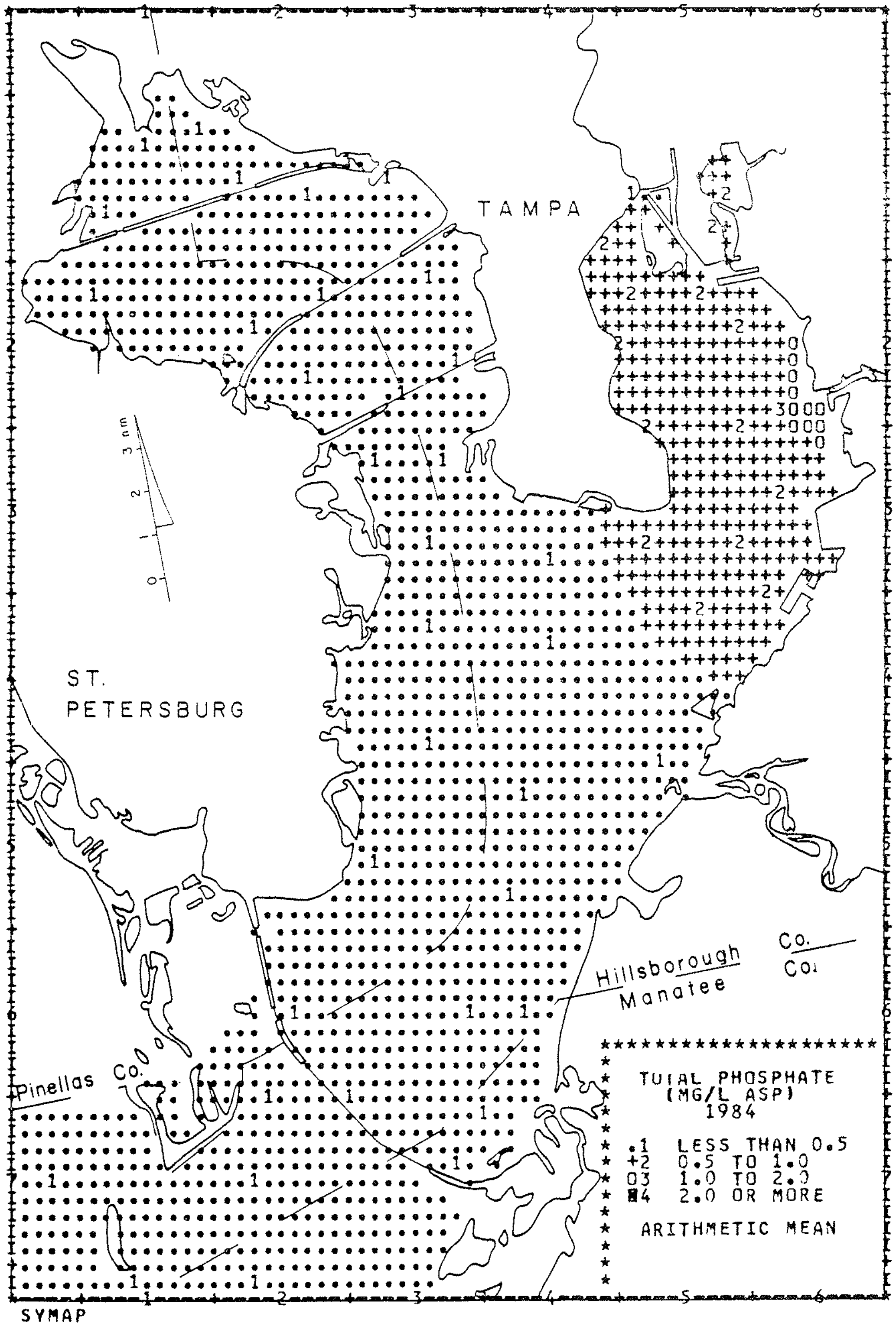

Figure 10. Mean annual total phosphorus, 1984 (Boler 1986).

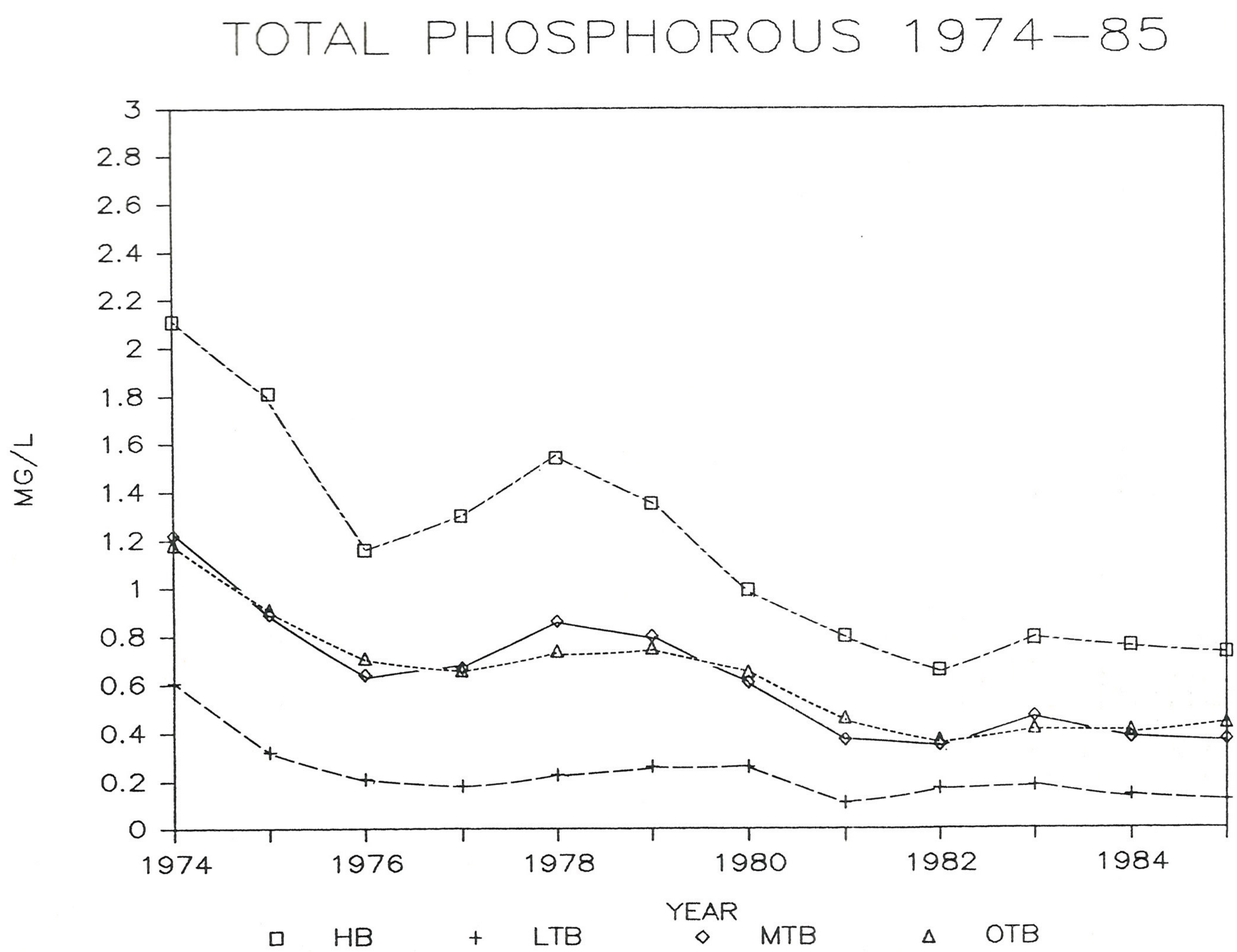

Figure 11. Annual trends in total phosphorus (Boler 1986).

declines in the Alafia River Basin. Even so, the north prong of the Alafia River had an annual average phosphorus concentration of 7.68 mg/l in 1984 (Boler 1986).

Nitrate-nitrite-nitrogen concentrations were relatively low in 1984, as in most years, with highest levels in Hillsborough Bay. Total Kjeldahl nitrogen concentrations were more uniform throughout the bay in the same year, with all but gulf stations with geometric means greater than 0.5 mg/l. (Ten-year trend analyses for nitrogen are unavailable because analytical methods changed in 1980.)

Dissolved Oxygen

In 1984 all mean annual bottom concentrations of dissolved oxygen were greater than 5.0 mg/l, except for McKay Bay, an arm of Hillsborough Bay. In the subsequent, wetter year of 1985, mean annual concentrations of dissolved oxygen at the bottom were less than 5.0 mg/l along the western shore of Hillsborough Bay and the shallow waters of middle Tampa Bay. In general, bottom dissolved oxygen minima were greater than 3.5 mg/l throughout all of Tampa Bay except Hillsborough Bay (Figure 12), although conditions in Hillsborough Bay are improving (Figure 13). Table 2 summarizes extreme dissolved oxygen conditions in Tampa Bay and accentuates Hillsborough Bay as the area of greatest fluctuation.

Table 1. Frequency (% total samples) of violations (<4.0 mg/l) and supersaturation of dissolved oxygen (adapted from Palmer and McClelland 1988).

Area	N	% Violations	% Supersaturated
Hillsborough Bay			
surface	1421	5	61
bottom	1408	20	33
Old Tampa BayZ			
surface	1478	0	56
bottom	1479	2	45
Middle Tampa Bay			
surface	1126	0	66
bottom	1123	3	39
Lower Tampa Bay			
surface	946	0	72
bottom	945	0	59

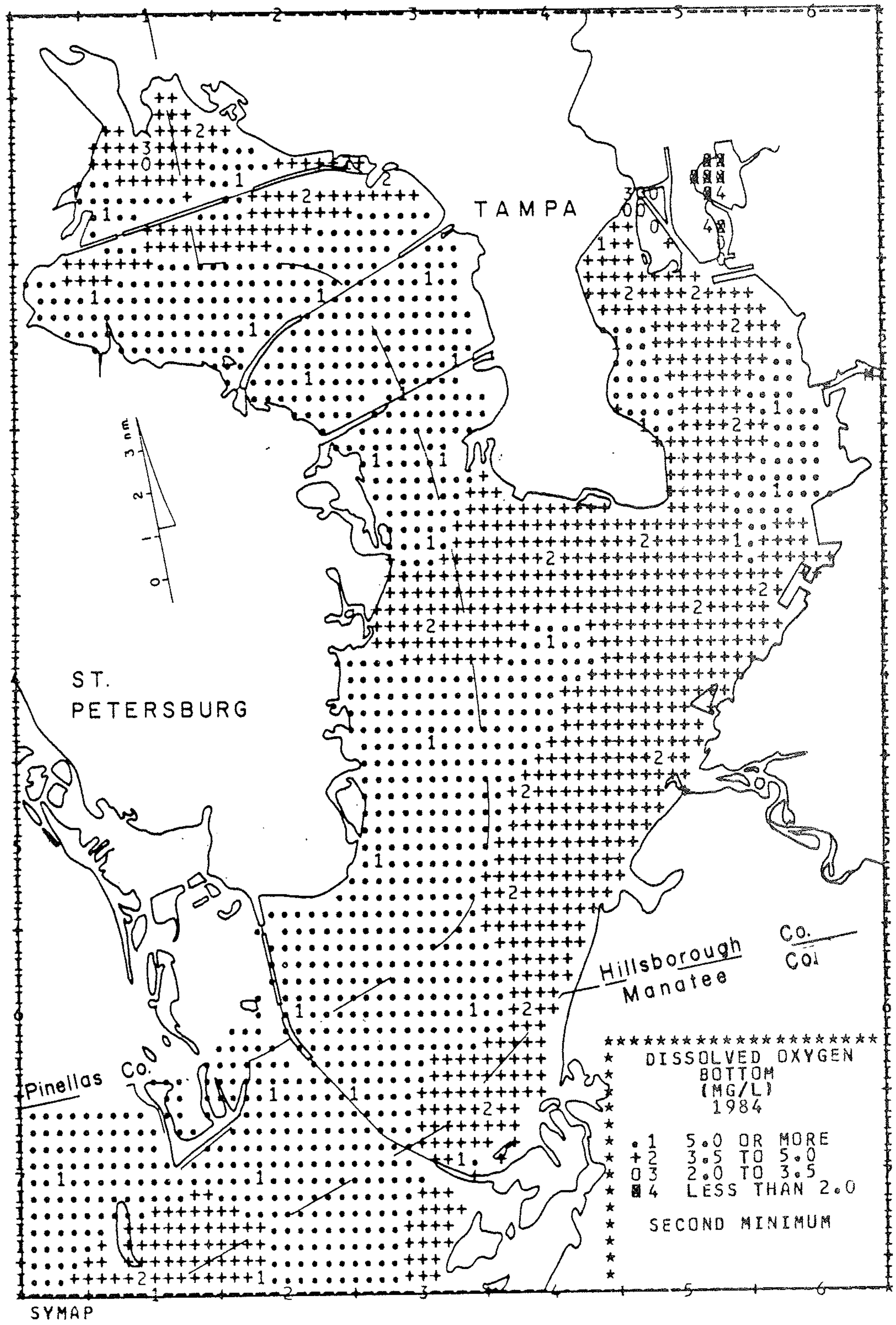

Figure 12. Means (based on second minima) of dissolved oxygen at the bottom, 1984 (Boler 1986).

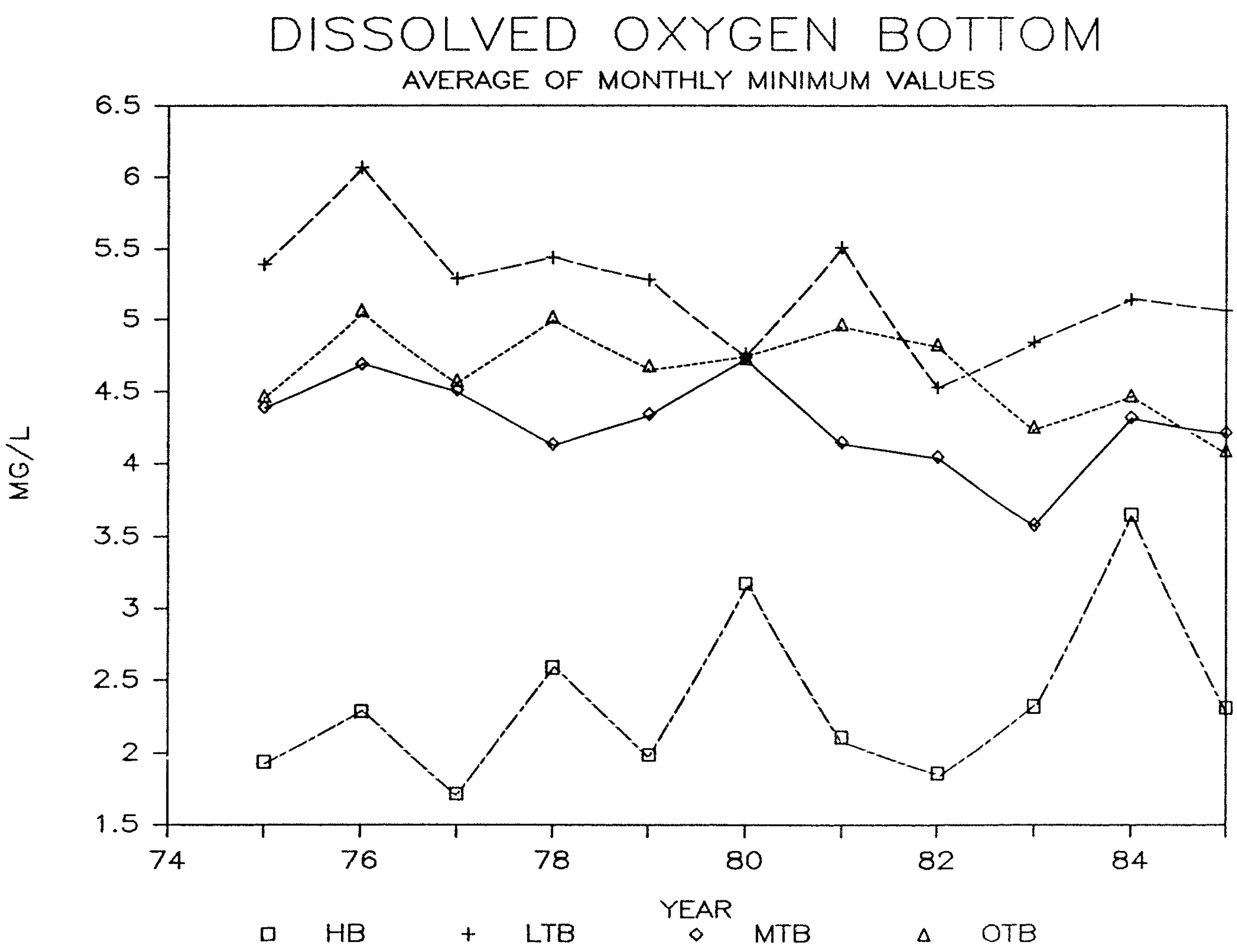

Figure 13. Annual trends in bottom dissolved oxygen (Boler 1986).

WATER QUALITY IS IMPROVING, BUT...

The State of Florida, local regulatory officials, and bay scientists presently believe that water quality of Tampa Bay is improving, and that such improvements are the result of active regulation and management. There have been tangible improvements since 1974 in many key parameters and rooted vegetation is reappearing in shallow waters of Hillsborough Bay. How long can these improvements continue; what emerging problems could undermine such progress; and what are the natural constraints to bay recovery?

Natural Conditions Affecting Water Quality

1. Weather

The bay areas experience one or two days of freezing temperature every year or two. Freezes result in fish kills in shallow waters and damage mangroves. Heavy leaf drop 1-3 months following freezes results in temporarily high detritus and particulate organic levels which are probably offset in subsequent years by reduced production in cold-damaged forests. Years of above-average rainfall or shorter periods following hurricanes result in heavy runoff, causing rivers to freshen throughout their length and the bays to have much lower salinity than usual. Heavy runoff also increases color and turbidity, and can result in fish kills due to salinity shock, periods of reduced oxygen, or both.

2. Anoxia

Hillsborough Bay is the only segment of either study area in which periods of partial to complete oxygen depletion have been documented. Oxygen stress is most severe near the bottom due to benthic respiration, phytoplankton self-shading, and the increased light path over channels dredged to 42 ft depths. Up to half of Hillsborough Bay's surface area has experienced oxygen stress in particular years, resulting in defaunation of benthic invertebrates. Defaunation corresponds to times of anoxia, which occur most often in July, August, and September (Santos and Simon 1980). The extent to which anoxia in Hillsborough Bay is a naturally occurring event is not known, but some anoxic conditions probably occurred prior to urbanization due to the combined discharges of three rivers in a naturally deep arm of the bay where wind-driven mixing is limited. Anoxia occurs in Charlotte Harbor (south of Sarasota Bay) due to discharge of the Peace River. Anoxia in the Harbor is considered to be a naturally-occurring event because that bay is relatively pristine, so part of the oxygen stress in Hillsborough Bay is probably natural as well.

3. Sediments

The bottom of Tampa Bay, especially Hillsborough Bay, exerts a substantial influence on water quality. Biota such as clams filter particulates from enormous volumes of bay water and seagrasses trap suspended sediment, but accumulations of fine, organic sediments play an even greater role by acting as sources --and sinks-- of nutrients. According to Ross et al. (1984), the benthos stores 84% of the carbon, 85% of the nitrogen, and 65% of the phosphorus moving through Tampa Bay's ecosystem. Preliminary estimates of flux rates are shown in Figure 14. The central role of sediments as a nutrient problem have caused engineers to propose either dredging or capping of the benthos. Others counter that sediment release of nutrients at high rates mean that benthic conditions will improve if given enough time without the heavy loadings which have occurred for almost a century. A detailed look at sediment-water interactions is given by Johansson and Squires, later in this report.

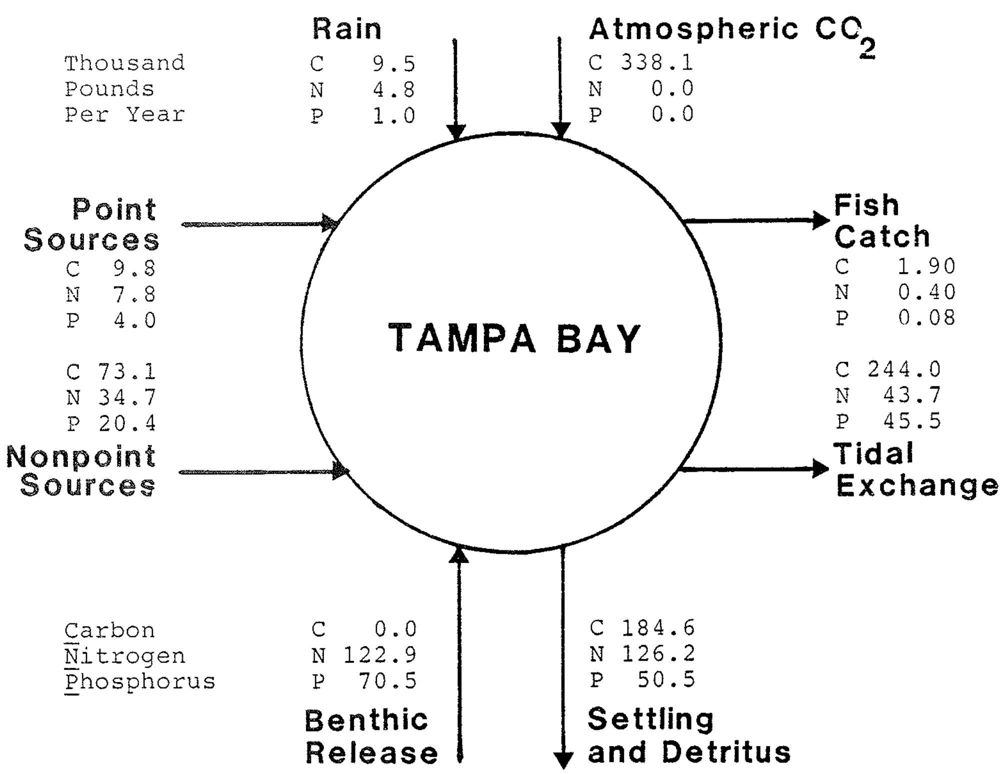

Figure 14. Nutrient sources and sinks, from Ross et al. 1984.

4. Red Tides

One of the most distinguishing features of Tampa and Sarasota Bays is their occasional entrapment of red tides, or blooms of the unarmored dinoflagellate, <u>Ptychodiscus</u> <u>brevis</u>. These blooms originate in offshore waters of the eastern Gulf of Mexico and move onshore with Loop Current eddys, wind, and nearshore currents. Once inshore, the blooms proliferate over huge areas, at times breaking into distinct cells and coalescing into larger masses at other times. The blooms occur once or twice every year or two. While there is no evidence that the frequency of blooms is greater than in past years there has been speculation that the duration of an inshore bloom may be prolonged by nutrient enrichment or other factors attributable to urbanization. Blooms cause fish kills, defaunate the benthos, and contaminate shellfish by oxygen depletion and the effect of their toxic metabolites. Aerosols produced in surf transport toxins inland causing human respiratory distress, and blooms generally inhibit tourism. Much needs to be learned about bloom initiation, maturation and transport, and about their ecological effects. Benthic infauna recolonize affected areas within 1-3 years, and recovery by other groups probably occurs over a 1-10 year period. These naturally occurring blooms, which may function similarly to wildfires in Florida's fire-maintained pine flatwoods, also deserve study in order to understand brown tides better in northeastern estuaries, which apparently are expressions of cultural eutrophication.

<u>Urban Conditions Affecting Water Quality</u>

Discharge of sewage treatment plant effluent and urban stormwater runoff pose the greatest continuing threat to water quality of Tampa Bay. Characteristics of STP discharge were presented at the seminar by John V. Betz, and Giovannelli's paper elsewhere in this report summarizes his presentation on stormwater.

The combined role of STP effluent and stormwater --plus agricultural and industrial loads-- was evaluated by Palmer and McClelland (1988) using a numerical model. The project, funded by the EPA with a grant for water quality studies under Section 205(j) of the Clean Water Act, concluded

> The problems in Tampa Bay appear to be related to nutrient enrichment and consequent high algal biomass: this can cause large dissolved oxygen variations and decreased light availability needed for seagrass growth. The nutrient and dissolved oxygen relationship along with the data and the modeling indicate that a bay-wide chlorophyll <u>a</u> value of 25 ug/l should be used as a maximum target for Tampa Bay in order to maintain good water quality. The historical data show that pockets of high chlorophyll <u>a</u> occur in Hillsborough Bay and the northwest corner of Old Tampa Bay. The modeling indicates that reduction of the chlorophyll-<u>a</u> in these pockets will protect the rest of the bay system. Therefore, if the targets are met in these pockets, the bay

in its entirety would be expected to meet the targets. The modeling showed that the low flow and high flow simulations with no point sources were considerably different and that little is gained during the low flow season with the imposition of BMP's [best management practices]. However, a significant improvement in the chlorophyll a concentration was predicted for Hillsborough Bay when agricultural and urban BMP's were considered for the year 2000 non-point source loadings. These simulations also included a limited nutrient discharge of the Alafia phosphate mines. It is recommended that in the Hillsborough Bay drainage basin, urban and agricultural BMP's be implemented in order to reduce the nutrient load in Hillsborough Bay. For Old Tampa Bay, due to the nature and size of the watershed, only small improvements are predicted with the imposition of BMP's. The non-point source simulations also indicate that the benthic fluxes of oxygen demand and of nutrients make a considerable difference in the condition of the bay. In particular, reduction of the fluxes to the low flow values for the high flow simulations resulted in a significant improvement in the bay.

The DER report's conclusion that BMP's may not significantly improve the bay speaks to the enormity of stormwater impact, if the report is a valid assessment. If it is not, much more evaluation will be needed. As the DER report acknowledged, point source impacts were not incorporated in the 1988 water quality assessment. Details of industrial discharges and major water quality impacts to the bay are given in Phillips et al., elsewhere in this report.

WATER QUALITY ISSUES IN BAY MANAGEMENT

Since 1972, state law requires domestic waste water disposal facilities discharging into tidal waters of west-central Florida (including Tampa and Sarasota Bays) to provide advanced waste water treatment (AWT). A modified version of the law is in effect today, although a period between 1980-81 and 1987 passed in which AWT requirements were relaxed and the Florida Department of Environmental Regulation was instructed to specify water-quality based effluent limitations (WQBEL) on a case by case basis. The WQBEL approach operates on the principle that a receiving water can only accept a certain load, irrespective of source, and that decisions are needed to allocate increments of waste load to specific sources.

Such waste load allocations could also be based on best available technology or impacts to living resources. In any case, some method is needed to analyze the combined effects of existing or proposed loads and the DER has used a numerical model of circulation and water quality for that purpose (although their original intent to base specific waste load allocations on model outputs has been modified by reinstatement of AWT requirements). Critics of the model's applications to waste load allocations support the scientific value of models and have called for a more comprehensive, ecosystem model of Tampa Bay, but challenge the concept of setting specific discharge limits using existing models which do not more completely address living resources, such as seagrasses. A new bay management program undertaken by the Southwest Florida Water Management District (see Perry's paper in this report) may be able to enhance existing models and begin development of an ecosystem model.

Either model could be used to incorporate ecological processes affecting water quality. Industrial inputs could be evaluated in terms of their cumulative impact, which if done for power generating stations alone would advance our ability to site new facilities or expand existing ones. The inputs of rivers must also be modelled with better accuracy. Ongoing basin-river-estuary studies in the Little Manatee River will be especially useful in this regard. Such inclusive models will be difficult to develop but are necessary to answer the fundamental bay management issues of what to improve, to what extent, and when, in order to gain how much benefit?

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BIOLOGY AND EUTROPHICATION OF TAMPA BAY

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BIOLOGICAL CHARACTERISTICS

Primary Producers

There are four principal groups of phytoplankton in Tampa Bay: phytomicroflagellates, diatoms, dinoflagellates and blue-green algae. The early studies of phytoplankton in the bay have been summarized by Steidinger and Gardiner (1985). These studies were initiated in response to the problem of blooms (cell counts usually greater than 50,000 per liter) of toxic dinoflagellates (*Ptychodiscus brevis*), known as "red tides", particularly the massive blooms of 1946-1947. The findings of all studies to date can be summarized as follows:

1. A north-to-south, or head-to-mouth, gradient exists in phytoplankton species numbers. In general, as one moves from the less saline upper portions of the bay to the more saline lower portions of the bay, water clarity and phytoplankton species numbers (or "richness") increase, while nutrient levels, chlorophyll 'a', and total phytoplankton cell counts decrease. The frequency of phytoplankton blooms and the eutrophic and turbid nature of the upper bay, particularly Hillsborough Bay, have been a common observation in recent years (Federal Water Pollution Control Administration [FWPCA] 1969; Simon 1974).

2. Nanoplankton (5-20 um) generally are the dominant size class of the phytoplankton. Small diatoms and microflagellates predominate, except when certain seasonal, monospecific blooms of species of blue-green algae (*Schizothrix*) or dinoflagellates (*Gymnodinium nelsonii*, *Ceratium hircus*, *Procentrum micans*, *Gonyaulax* spp. and others) dominate in Hillsborough Bay and Middle Tampa Bay.

3. At least 272 species of phytoplankton occur in the bay: the majority (167) are diatoms.

4. Short-term fluctuations in species composition and standing crop are common. Seven-fold to ten-fold differences are reported within one tidal cycle.

5. The majority of the bloom species are resident in the bay but significant blooms occasionally occur due to species which invade from the Gulf of Mexico. Blooms of the toxic species Ptychodiscus brevis originate 16-60 km offshore, for reasons as yet unclear, and are carried into the bay. Between 1946 and 1982, such invasions occurred at least 12 times.

6. Many of the previous studies utilized analytical procedures which limit the quantitative comparison of all data; some uniform sampling strategy and analytical procedures are needed to make future data more usable. Quarterly sampling and ignoring the nanoplankton in taxonomic and production studies are two of the problem areas.Primary production studies of phytoplankton in Tampa Bay have been summarized by Johansson, Steidinger and Carpenter (1985). Table 1 lists the annual rates reported in several studies using three different methods. Whether the different values over time reflect a real increase in primary production by phytoplankton or simply the results of different methods cannot be determined at present.

Table 1. Estimated annual phytoplankton production rates in the Tampa Bay system (g $C/m^2/yr$). From Johannson et al. 1985.

Dates and Methods	Old Tampa Bay	Hillsborough Bay	Middle Tampa Bay	Lower Tampa Bay
1968 Chlorophyll + light	170	270	170	120
1965-67 Oxygen	430	610	440	220
1969-72 Chlorophyll + light	290	580	490	180
1973-83 Carbon isotope	--	620	620	--

Earlier data may be of limited value due to the methods used (lack of grinding), which probably produce an underestimate of chlorophyll 'a' in eutrophic waters; however, it is reasonable to assume a real increase in phytoplankton production due to eutrophication. Annual production of 340 g C/m^2 is suggested as a reasonable estimate for phytoplankton primary production in the deeper portions of Tampa Bay, and 509 g C/m^2 for shallower portions, based on the available data (Johansson et al. 1985).

Epiphytic (living on plants) microalgae are treated here as a group separate from other benthic algae because of their apparent importance in food webs in other Florida estuarine systems (Fry 1984), and because those found growing on seagrass leaves in Tampa Bay have received some study (Dawes 1985). The most common epiphytes are species of _Champia_, _Lomentaria_, _Polysiphonia_, _Acrochaetium_, _Fosliella_, _Hypnea_, _Spyridia_, _Cladosiphon_, _Ectocarpus_ and _Cladophora_. The possible importance of epiphytic algae in the food web and the general health of seagrasses in a eutrophic estuary like Tampa Bay are discussed later. It is sufficient to note here that the abundant caridean shrimp and amphipods found in Tampa Bay seagrass meadows have been shown elsewhere to depend heavily on seagrass algal epiphytes as a source of food (Orth and Van Montfrans 1984). It is likely that the same dependence would be found here.

Macroalgae are abundant in Tampa Bay, and the 221 identified species from the bay represent a greater diversity than that reported for any other estuary in Florida (Dawes 1985). Red and green algae predominate, with brown algae being more abundant in the winter and early spring, although still not dominant.

Most studies of macroalgae in the bay have been taxonomic or physiological in nature (Dawes 1985); have focused on the overabundance of certain pollution indicator species (_Ulva_ spp., _Gracilaria_ spp.) which cause aesthetic problems (FWPCA 1969); have been implicated in the elimination of seagrass meadows from certain parts of the bay (Guist and Humm 1976); or have anecdotally reported consumption of macroalgae by manatees (Lewis, Carlton and Lombardo 1984). The FWPCA (1969) studied the abundance and distribution of macroalgae in Hillsborough and Old Tampa Bay to determine the source of odor problems reported by residents along the western shore of Hillsborough Bay. The study concluded that the odors were caused by excessive nutrient concentrations which led to massive blooms of the macroalga _Gracilaria tikvahiae_. This species, in turn, was killed by normal salinity reductions during times of heavy rainfall and decayed to produce the odor.

Rates of primary production by Tampa Bay macroalgae, of approximately 70 g C/m^2/yr, have been measured in both laboratory and field experiments (Hoffman and Dawes 1980; Dawes 1985). The data are very sparse, and much additional work is needed, especially seasonal field measurements.

Seagrasses are submerged flowering plants with true roots and stems, and are quite different from "seaweeds" (macroalgae), which are nonflowering algal species without true roots. Lewis, Durako, Moffler and Phillips (1985) reported that five of the seven species of seagrass known from Florida are found in Tampa Bay: _Thalassia testudinum_ (turtle grass); _Syringodium filiforme_ (manatee grass); _Halodule wrightii_ (shoal grass); _Ruppia maritima_ (widgeon grass); and _Halophila engelmannii_ (star grass).

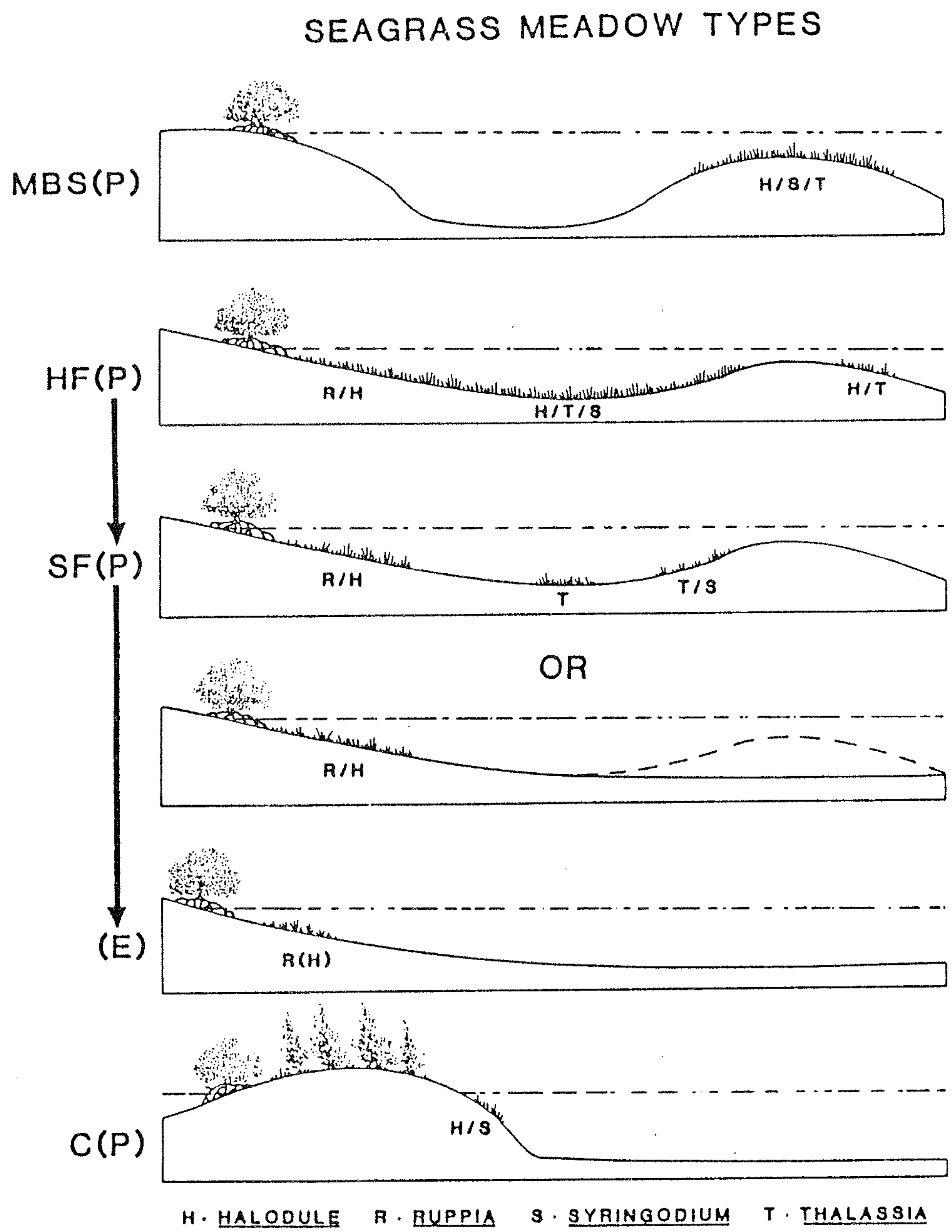

Figure 1. Seagrass meadow types. MBS(P) - mid-bay shoal perennial; HF(P) - healthy fringe perennial; SF(P) - stressed fringe perennial; (E) - ephemeral; C(P) - colonizing perennial. From Lewis et al. 1985.

Seagrass meadows now cover 5,750 ha of the bottom of the bay. Based on historical aerial photography and maps, it is estimated that seagrasses once covered 30,970 ha of the bay. This 81% loss has had severe effects on the bay's fisheries (Lombardo and Lewis 1985).

Box cores taken at 18 stations in the bay over a one-year period (Lewis et al. 1985) showed that seagrass meadows in Tampa Bay are largely monospecific, with approximately 40% being turtle grass, 35% shoal grass, 15% manatee grass, and 10% widgeon grass. Star grass was seen infrequently. Lewis et al. (1985) defined five types of seagrass meadows in the bay, based on location, form, and species composition (Figure 1): 1) mid-bay shoal perennial, MBS(P); 2) healthy fringe perennial, HF(P); 3) stressed fringe perennial, SF(P); 4) ephemeral, E; and 5) colonizing perennial, C(P). The idealized cross-sections in Figure 2 are derived from actual transects established during 1979-1980 (Lewis and Phillips 1980). It is hypothesized that Types 2-4 are stages in the eventual disappearance of a seagrass meadow due to human-induced stress, as illustrated by the arrows in Figure 1.

As noted by Lewis et al. (1985), most of the work to date on seagrass meadows in Tampa Bay has concentrated on descriptive biology (distribution, reproduction, infaunal communities). The elucidation of the functional role of seagrass meadows in the bay in terms of value as a food source (direct herbivory, detrital, drift and epiphytic algal component) and habitat is being initiated only now, primarily in relation to larval fish use. Even estimates of total primary production by seagrasses are hampered by the lack of comprehensive baywide seasonal data.

It is likely that seagrass meadows in Tampa Bay are important habitat for benthic invertebrates and certain juvenile species of fish. Virnstein, Mikkelsen, Cairns and Capone (1983) noted in their studies in the Indian River that seagrass meadows had a density of infaunal invertebrates three times that of unvegetated sediments, and that epifaunal organisms were 13 times as abundant in seagrass as in sandy areas. Zieman (1982) noted that eight sciaenid species have been associated with seagrass meadows in southwestern Florida, and that juvenile spotted seatrout (*Cynoscion nebulosus*), spot (*Leiostomus xanthurus*) and silver perch (*Bairdiella chrysoura*) are commonly found in seagrass beds. Sheepshead (*Archosargus probatocephalus*) and snook (*Centropomus undecimalis*) also use seagrass meadows as habitat during their life cycles (Odum and Heald 1970; Gilmore et al. 1983).

Similar data for seagrass meadows in Tampa Bay are sparse, but the existing data support the importance of seagrass meadows as habitat for fish and invertebrates. Studies of fish populations in Tampa Bay indicate that seagrass meadows are one of several important nursery habitats for juvenile fish (Springer and Woodburn 1960; Comp 1985). Collections by Springer and Woodburn (1960) at two areas containing mixed seagrass and algae had the highest number of species (108 and 93, respectively, of a total of 253 species). The lowest number of species, 48, was reported from an unvegetated sandy beach station.

The vegetation of emergent wetlands in Tampa Bay consists of various mixtures of five major plant species, two of which are tidal marsh species, black needlerush (*Juncus roemerianus*) and smooth cordgrass (*Spartina alterniflora*), and the remaining three being mangroves. Minor species in these tidal marshes include leather fern (*Acrostichum danaeofolium*), the brackish water cattail (*Typha domingensis*), and bulrush (*Scirpus* spp.).

Estimates of the percentage of the total emergent wetlands which are tidal marsh vary from 10% to 18% (Estevez and Mosura 1985; E. Pendleton, [U.S. Fish Wildlife Service, Slidell, Louisiana] pers. comm.). Mangroves are the dominant vegetation, but periodic freezes allow substantial areas of tidal marsh to persist as cold-sensitive mangroves are pruned or killed (Estevez and Mosura 1985). These authors also noted that "regrettably little is known of the organization or functioning of tidal marshes in Tampa Bay".

In contrast to tidal marshes, mangrove forests on the bay have received some study (Estevez and Mosura 1985), although it has been primarily descriptive in nature. The forests are composed of three species (Figure 2); red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*). Unlike mangrove forests farther south (Odum and Heald 1972), mangrove forests on Tampa Bay are composed of a mixture of all three species, and while exhibiting natural zonation similar to that described by Davis (1940), have some unique features (Estevez and Mosura 1985; Lewis et al. 1985).

The latitude of Tampa Bay is near the northern limit of the distribution of mangroves, and low temperature stress is common in the mangrove forests. Repetitive freezes can intensify temperature effects on the structure of the forest. Initially, the canopy is partially destroyed; if another freeze quickly follows, the damaged trees are killed. In recent years, two freezes have occurred relatively close together (1977 and 1983). During January 1977, a minimum temperature of $-5^{o}C$ was reached and snow fell for the first time in more than 100 years. The Christmas freeze of 1983 involved two days during which the temperature in Tampa fell to $-6.7^{o}C$, followed by $-7.2^{o}C$ the next day. Such low temperatures had not occurred in Tampa since the historical freeze of 1894-1895 dealt a serious blow to the then flourishing citrus industry in Florida. The freezes in 1977 and 1983 caused significant losses of mangroves, and the total area of tidal marsh on the bay may increase as more cold-tolerant marsh plants invade areas left barren by the death of the mangroves (Figure 3). Selective survival of mangroves has been observed during a less severe frost or freeze, with the black mangrove having the greatest resistance to freeze damage and the white mangrove the least. The black mangrove is typically the largest diameter tree in the forest (Table 2), particularly in the fringe and overwash forests which are the dominant types in the bay.

Figure 2. Healthy mangrove forest dominated by black mangroves (Avicennia germinans), Middle Tampa Bay, March 1983.

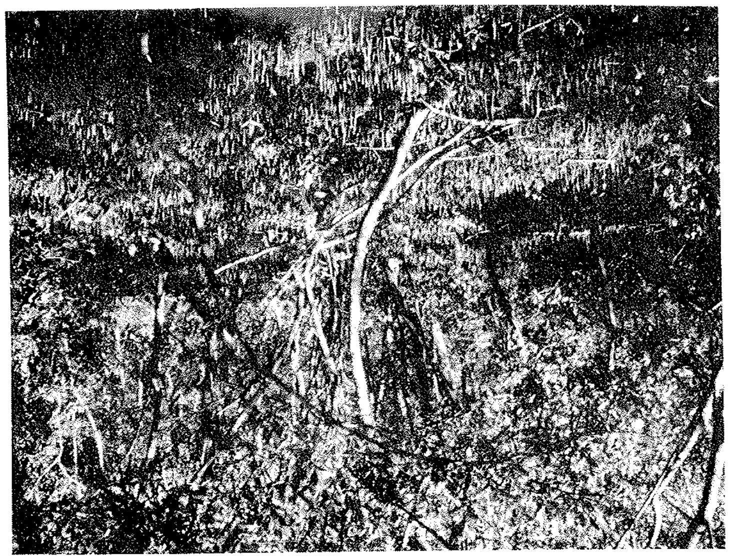

Figure 3. Freeze damaged mangrove forest (dominated by black mangroves), Old Tampa Bay, April 1986.

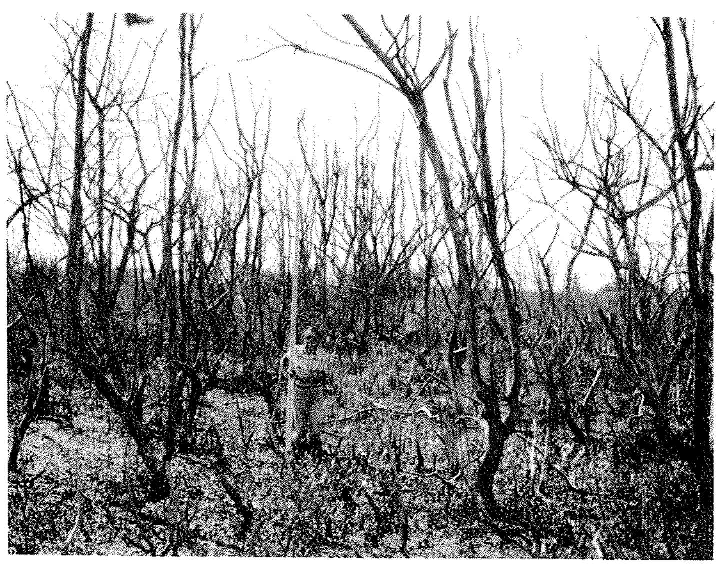

Table 2. Mangrove tree size by species and forest type in Tampa Bay (Williamson and Mosura 1979). DBH - diameter at breast height. numbers in parentheses are sample sizes.

	CUMULATIVE MEAN DBH (cm)		
Forest type	Rhizophora	Avicennia	Laguncularia
Fringe	2.69 + 2.26 (139)	4.59 + 3.16 (186)	2.31 + 2.64 (203)
Overwash	3.37 + 2.04 (90)	5.27 + 1.37 (7)	
Tributary	2.91 + 2.01 (50)	1.85 + 0.99 (17)	2.57 + 0.38 (10)

Although the necessary habitat utilization studies have not been conducted for Tampa Bay, the value of mangroves to Florida's fisheries is well documented (Lewis et al. 1985). Mangroves are known to serve as one of several critical habitats in the life history of many fish and shellfish species important in commercial and recreational fisheries, including pink shrimp (Penaeus duorarum), redfish or red drum (Sciaenops ocellatus), tarpon (Megalops atlanticus), and snook (Centropomus undecimalis) (Odum, McIvor and Smith 1982; Lewis et al. 1985; Haddad, this volume).

All major rivers and streams entering the bay have floodplain forests and adjacent wetlands that drain eventually into the bay. These freshwater wetlands serve as the first of a series of filters to cleanse upland drainage before it enters the bay, and they also act as contributors of dissolved and particulate organic matter and nutrients.

Typical of these wetlands are those bordering the Alafia River. Clewell, Goolsby and Shuey (1983) described these wetlands as supporting 409 plant species, including 84 tree species, dominated by red maple (Acer rubrum) and swamp tupelo (Nyssa biflora).

Total streamflow input to Tampa Bay is estimated to average 2,011 cfs (Flannery, this report). If it can be assumed that total organic carbon concentration (TOC) averages 10 mg C/l (Dooris and Dooris 1985), then TOC input via streamflow would be 2 x 107 kg C/yr. TOC measurements of this sort are typically made on unfiltered water samples, but do not take into account bedload transport of organic material derived from adjacent wetlands and uplands, or pulse events when large amounts of organic matter may be moved in a relatively short period of time. For this reason, the above input value should be considered conservative.

Total net primary production (carbon reduced by photosynthesis) by natural plant communities in Tampa Bay (listed by category in Table 3) is estimated at 478.2×10^6 kg/yr. These figures indicate that Tampa Bay can be characterized as a phytoplankton-based system when compared to other sources of net primary production. By virtue of their high annual production, mangroves are the second most important primary producer in the estuary.

In addition to primary production, organic material can be transported to the bay from outside sources by streamflow, sewage discharges, urban runoff from pavement, rainfall, and groundwater discharge. These values account for a total input of organic carbon of 92.7×10^6 kg/yr, or about 25% of the amount produced by photosynthesis (or marine plants) in the bay. This figure was probably much higher prior to recent improvements in industrial and municipal discharges, and substantial deposits of residual organic matter are still present in bay sediments (Ross, Ross and Jerkins 1984). The estimate by those authors of current allochthonous sources of organic carbon is somewhat less, 66.7 vs. 92.7×10^6 kg/yr.

Table 3. Estimated annual production of primary producers based on areal coverage in the Tampa Bay system (modified from Johansson et al. 1985).

PRIMARY PRODUCER	PRODUCTION ($g\ C/m^2/yr$)	AREA (km^2)	TOTAL PRODUCTION ($g\ C/yr \times 10^6$)	PERCENT OF TOTAL
Seagrass and epiphytes	730	57.5	42.0	8.5
Macroalgae	70	100.0	7.0	1.4
Benthic microalgae	150	200.0	30.0	6.0
Mangrove forests	1,132*	64.5**	73.0	14.7
Tidal marshes	300	10.5**	3.2	0.6
Phytoplankton (areas >2m deep)	340	864.0	293.8	59.1
Phytoplankton (areas <2m deep)	50	96.0	48.0	9.7
Riverine forests	--	no data available.		

*Estevez and Mosura 1985.
**Assuming 14% of the bay's emergent wetlands are tidal marsh.

Secondary Production

Secondary producers are the animal communities, either herbivorous or carnivorous, that consume the organic carbon in an area. A simplified food web for the bay is shown in Figure 4. Ideally, one should be able to measure the amount of fish or crab biomass produced over a period to time; this is total secondary production. Data on secondary production in Tampa Bay have not been generated accurately.

In order to understand how the bay works, it will be important to quantify both the types and amounts of primary and secondary production. Simply having large amounts of both may not necessarily be ideal. A bay ecosystem with a large variety of plant and animal species actually may require less organic material input. The typical "green pea soup" appearance of a polluted pond or sewage treatment plant lagoon is an example of high primary production that also indicates an unbalanced system. Proper management of Tampa Bay to provide stable, balanced populations without abnormal algal blooms and fish kills will require a better understanding of both primary and secondary production.

The most extensive study of holoplankton to date (Hopkins 1977) provides much useful data, but the author emphasized that collections were taken only the the surface of the bay once every three months (quarterly) for one year. The data are of limited value in describing long term cycles but are essential as a first step in describing the general characteristics of the bay zooplankton. Thirty-seven species of holoplankton were identified in the study, and were grouped into three categories based on abundance. Mean biomass of all zooplankton was 39.6 mg dry wt/m^3. The dominant species were three copepods (*Oithona colcarva*, *Acartia tonsa*, *Paracalanus crassirostris*), which made up 56% of the zooplankton biomass.

Meroplankton is composed of two groups, invertebrate and fish meroplankton (ichthyoplankton). Meroplankton data for Tampa Bay have been summarized by Weiss and Phillips (1985). Hopkins (1977), in sampling for holoplankton, found that 19% of total zooplankton number and 8% of the total biomass (3.2 g dry wt/m^3) were meroplankton.

The benthic community consists of animals that live in the sediment as infauna by burrowing or forming permanent or semi-permanent tubes extending just above the sediment surface; animals that live on the sediment surface either as mobile epifauna or sedentary epifauna; and animals that form specialized communities such as oyster reefs or live-bottom communities.

Taylor (1973), Simon (1974), and Simon and Mahadevan (1985) summarized the benthic studies conducted in Tampa Bay. These studies have resulted in the following general conclusions regarding this group of invertebrates in Tampa Bay:

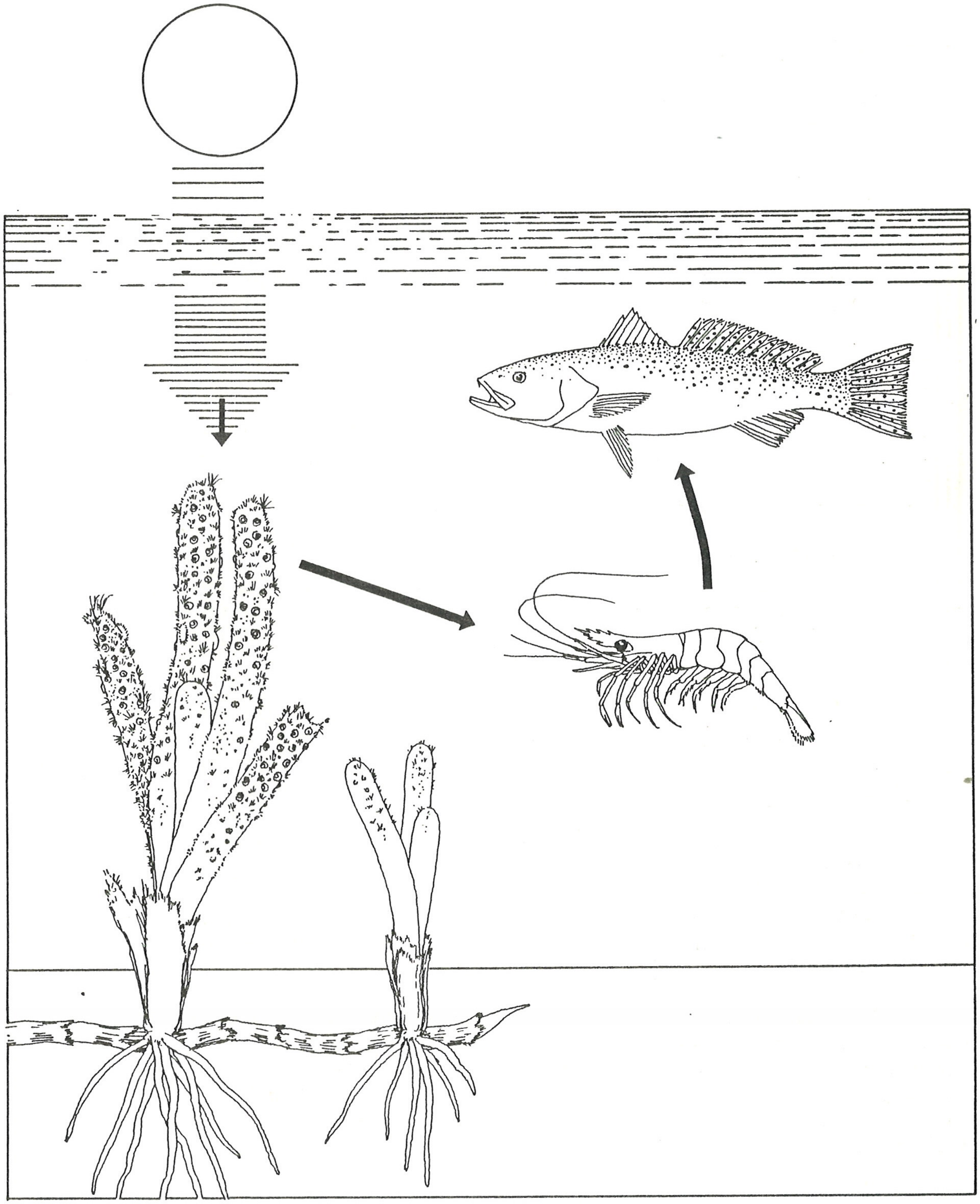

Figure 4. Idealized marine food chain elements.

1. The estuary supports "an extremely abundant and diverse assemblage of bottom organisms, except in Hillsborough Bay, dredged regions of Boca Ciega Bay, and a system of inland canals developed in upper Tampa Bay" (Taylor 1973). Taylor listed 207 species of polychaetes, 231 species of mollusks, and 29 species of echinoderms found in the bay. Simon and Mahadevan (1985) stated that approximately 1,200 infaunal and epifaunal species (excluding meiofauna) occur in the bay.

2. Seasonal fluctuations in the abundance and diversity of these organisms are pronounced. Seasonal variability in benthic populations is high and densities can range from zero to 200,000/m^2, particularly in areas of pollution-related stress.

3. Seagrass beds have declined, with a concomitant decrease in faunal diversity.

4. Opportunistic and "pollution indicator" species are abundant, particularly in Hillsborough Bay where pollution problems have been well documented for many years. Both Santos and Simon (1980) and Dauer (1984) noted that parts of the bay periodically undergo catastrophic disturbance due to anoxia (lack of oxygen). This condition was first documented by the FWPCA (1969) and the National Marine Fisheries Laboratory (Taylor, Hall and Saloman 1970) during the mid-1960s, and is similar to conditions reported in Chesapeake Bay (Officer, Biggs, Taft, Cronin, Tyler and Boynton 1984) as far back as the 1930s.

5. Sediment type appears to be a controlling factor in determining infaunal distributions in the bay. Bloom, Simon and Hunter (1972) sampled along three shallow shoreline transects in Tampa Bay, each with a distinct sediment type (mud, sand, muddy sand). They concluded that benthic assemblages along two of the transects were distinct, and the assemblage along the third was a composite of the other two.

6. A general increase in species richness and decrease in total population abundance are evident on a north-to-south gradient in the bay.

Springer and Woodburn (1960) listed 253 species of fish found in the Tampa Bay area. Additional studies raised the total number to 312 (Springer and McEarlean 1961; Moe and Martin 1965). Comp (1985) noted that many of these were offshore species and would likely never be found in the bay. He prepared a list of 203 species which were actually collected within the bay. He believed that only 125 of these could be considered common inhabitants, and although the list indicates a diverse fish assemblage, ten or fewer species usually made up the majority of the fish caught in sampling programs. Table 4 lists the ten most common fish in Tampa Bay in terms of numerical abundance in collections made with standard gear. As both Springer and Woodburn (1960) and Comp (1985) emphasized, the standard gear used for sampling of fishes in the bay is biased toward capturing smaller, less mobile species. For example, sharks and rays are abundant in Tampa Bay, but are rarely sampled due to their mobility and size. Even mullet are probably undersampled, although they are one of the most abundant species in the bay.

Tampa Bay is a nursery area for the larvae and juveniles of 79 resident and migratory fish species. Most spawning occurs during the spring and early summer in either the nearby Gulf or the bay proper, usually in higher salinity areas. During and following these spawning periods, the larval and juvenile fish typically migrate into shallow, protected, low salinity nursery areas of the bay to feed and mature (Comp 1985; Lewis et al. 1985).

Only two species of marine reptiles are common in the bay, the diamondback terrapin (*Malaclemys terrapin macrospilota*) and the mangrove water snake (*Nerodia fasciata compressicauda*). Both are common in localized areas, but have not been studied. Loggerhead turtles (*Caretta caretta*) are occasionally observed in the bay on the Gulf side of Egmont Key (Reynolds and Patton 1985).

Table 4. The ten dominant fish species in Tampa Bay, listed in approximate order of abundance, with notation as to area of the bay where found (modified from Springer and Woodburn 1960; Finucane 1966; Comp 1985).

SPECIES	COASTAL BEACHES high salinity	LOWER TAMPA BAY medium to high salinity	MIDDLE TAMPA BAY medium salinity	HILLSBOROUGH & MCKAY BAYS low salinity
Tidewater silverside *Menidia peninsulae*	X	X	X	X
Bay anchovy *Anchoa mitchilli*		X	X	X
Scaled sardine *Harengula jaguana*	X		X	X
Striped mullet *Mugil cephalus*		X	X	X
Pinfish *Lagodon rhomboides*		X	X	X
Longnose killifish *Fundulus similis*		X	X	X
Spot *Leiostomus xanthurus*		X	X	X

Table 4. continued.

SPECIES	COASTAL BEACHES high salinity	LOWER TAMPA BAY medium to high salinity	MIDDLE TAMPA BAY medium salinity	HILLSBOROUGH & MCKAY BAYS low salinity
Silver perch *Bairdiella chrysoura*		X	X	
Silver jenny *Eucinostomus gula*		X	X	
Code goby *Gobiosoma robustum*		X	X	

Seabirds and wading birds are a very visible and important component of the animal life of the bay. Because they are relatively easy to observe, counts and species observations are abundant. Eighty-three species of birds are associated with marine habitats in the bay. Many of these use certain bay habitats for nesting and raising young, and also wade in the shallows or dive in deeper waters to feed on fish and invertebrates.

The Brown Pelican (*Pelecanus occidentalis*) is particularly well studied (Woolfenden and Schreiber 1973; Schreiber and Schreiber 1983). The adults nest in the canopy of mangroves on natural or artificial islands in the bay where they are protected from mammalian predators (e.g., raccoon, *Procyon lotor*) which typically do not swim across water barriers.

The total breeding population of colonial birds in Tampa Bay is estimated to be 75,000 pairs, two-thirds of which are Laughing Gulls (Paul and Woolfenden 1985). The Laughing Gull population is estimated to be one-third of the entire breeding population in the southeast United States. The Brown Pelican population of 2,700 to 3,000 breeding pairs represents nearly one-third of the entire Florida population. In 1983, an estimated 10,200 pairs of White Ibis were present in one large colony at the Alafia River (Paul and Woolfenden 1985).

McKay Bay, in the northeast part of Tampa Bay, typically supports a winter population of almost 25,000 marine birds, which during eleven years of censusing, have included 75 species. Almost 80% of these are five species: Lesser Scaup, Ruddy Duck, Dunlin, Short-billed Dowitcher, and Western Sandpiper (Paul and Woolfenden 1985).

Although some species which formerly nested in the bay have returned recently (Reddish Egret in 1974, Roseate Spoonbill in 1975), recent population declines in many species are apparent. Paul and

Woolfenden (1985) listed red tides, parasite outbreaks, dredge and fill activities, pesticide use, and oil spills as having generally negative effects on bird abundance. Waterfowl surveys of the bay have indicated a sharp deline in the winter population of Lesser Scaup, from 105,900 in 1976 to 8,400 in 1979. Major dredging in Hillsborough Bay is implicated as a possible cause of the decline, because over 400 ha of open water habitat was lost during this period as a consequence of spoil island creation.

Reynolds and Patton (1985) have summarized the existing information on marine mammals of the Tampa Bay area. Only two species are normally found within the bay, the bottlenose dolphin (Tursiops truncatus) and the West Indian manatee (Trichechus manatus). The bottlenose dolphin is a year-round resident and the local population is estimated at 100-200 individuals, found in small herds of three to six animals (Reynolds and Patton 1985).

In a baywide survey over a period of one year, Patton (1980) found that numbers of manatees varied seasonally; a maximum of 55 was observed in the winter. They appeared to congregate around industrial thermal discharges into the bay. The largest single aggregation was 42 individuals, observed around the mouth of the Alafia River in February 1980. Lewis et al. (1984) observed manatees feeding on macroalgae in the same area in January 1981.

There is a general absence of studies on ecological relationships in the bay. Unlike studies in Apalachicola Bay (Livingston 1984), most scientific work in Tampa Bay has been basically descriptive, or has concentrated on a single structural or functional aspect of the bay's ecology. Future studies need to address four topics concerning ecological relationships in the bay: 1) energy sources; 2) abiotic controls in communities; 3) plant and animal interactions; and 4) fisheries habitats.

The flow of energy from the sun through plants to the animal communities of the bay is illustrated in Figure 5. None of the boxes or arrows have numbers associated with them because the specific quantities of energy contributed to the various animal groups by the major plant types have not been made. Table 1 lists phytoplankton as the source of 68.8% of the bay's primary production. This does not mean that phytoplankton provide 68.8% of the energy consumed by animals in the bay, because the quantity of energy captured by phytoplanktonic photosynthesis that is subsequently lost to sedimentation and flushing to the bay is unknown. Because of eutrophication, it is likely that much phytoplankton productivity is incorporated as organic deposits in the bottom of the bay, and may contribute to anoxic conditions reported in Hillsborough Bay (Johansson and Squires, this volume). Similar events have been attributed to high phytoplankton productivity in Chesapeake Bay (Officer et al. 1984).

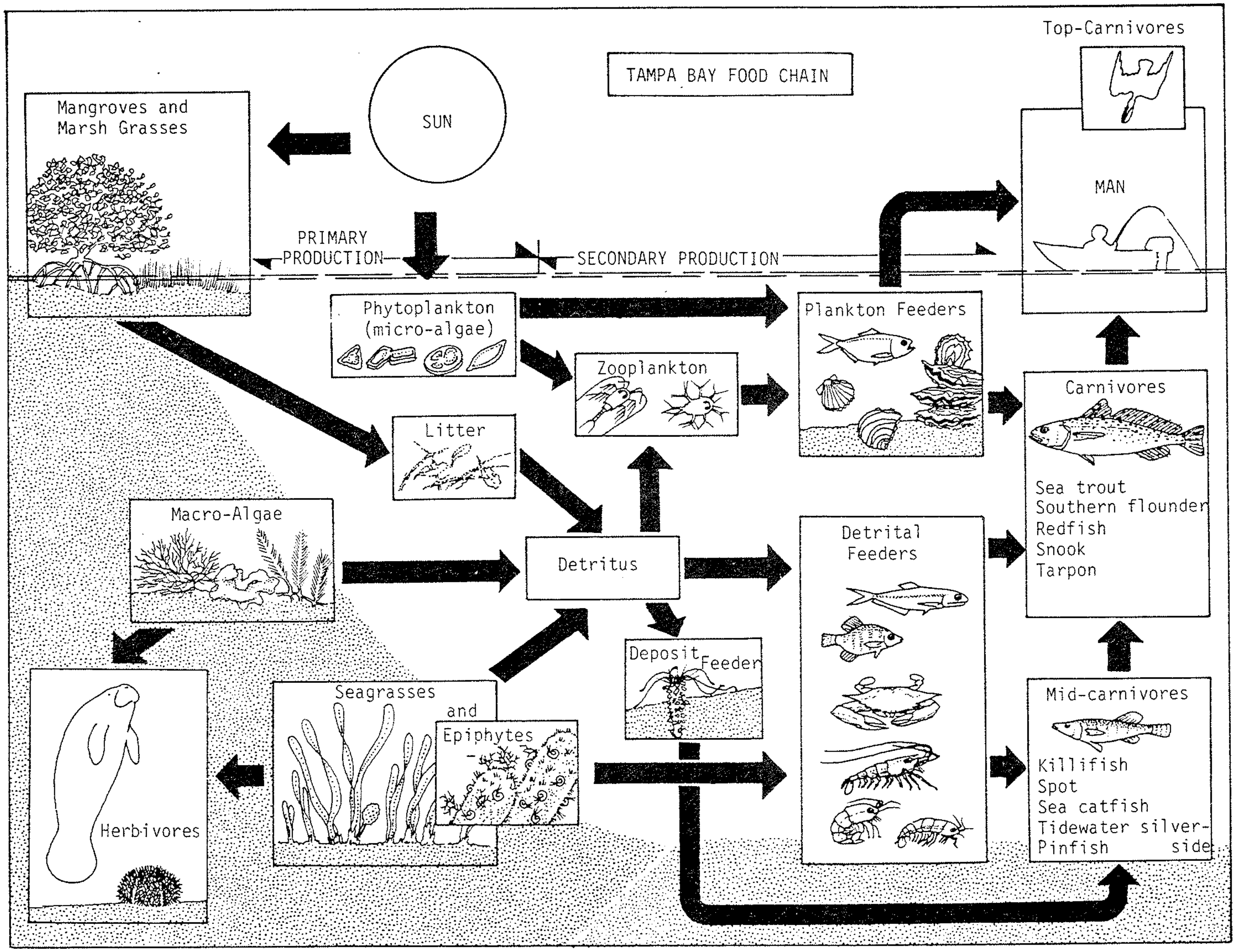

Figure 5. Generalized food web for Tampa Bay.

The annual cycles of temperature and rainfall, and the common events of red tides, hurricanes, drought and frost, are the basic controlling factors for all life cycles in the bay. However, no attempts have yet been made to statistically correlate physical factors to biological variables in the bay. Within the anlayses of some individual studies, distinct correlations are demonstrated. Without these analyses, conclusions as to cause and effect in bay processes can be erroneous. An example is the general anecdotal observation that water clarity in the bay is improving; this is often attributed to improved sewage treatment at such plants as the City of Tampa's Hookers Point facility. Trends in water clarity and chlorophyll a (Estevez, this report) tend to support these observations. What is not taken into account is the fact that several recent winters have been the coolest in 100 years, and rainfall has been less than average. Both of these climatological features could potentially contribute to reduced phytoplankton populations and increased water clarity. To illustrate, Flint (1985), in examining eleven years of biotic and abiotic data for Corpus Christi Bay, noted that episodic events (floods, hurricanes) stimulated estuarine productivity and thus represented a significant forcing factor to the estuary. He stated (p. 168) that "without the reconstruction of a long-term data set ... these perceptions of ecosystem function could not have been developed".

Unfortunately, we do not have simultaneous, long-term data sets of abiotic and biotic information from which to draw similar conclusions about Tampa Bay. Although large amounts of abiotic data are collected, there has been no similar effort toward the collection of concurrent biotic community data. The problems of understanding the role of physical parameters in bay processes are immense but without that understanding, decisions on bay management will continue to be made on the basis of symptomatic, rather than causative, considerations.

In addition to their role as sources of energy, plant communities in the bay are important as habitat for animals. Certain species are found in particular habitats at certain times of the year. For example, Brown Pelicans seek out the mangrove islands for nesting during the spring (Paul and Woolfenden 1985), and young pinfish are found in large numbers in seagrass meadows at about the same time (Springer and Woodburn 1960). Quantitative sampling of fauna has been limited largely to benthic infauna in unvegetated habitats. The studies of polychaetes in a seagrass meadow (Santos and Simon 1974) and of invertebrates in a mangrove forest (Lewis 1983) are two of the few exceptions.

The assumption is made that the loss of certain vegetated habitats has contributed to declines in fish and wildlife in the bay (Hoffman, Durako and Lewis 1985; Lewis et al. 1985; Paul and Woolfenden 1985), and that re-establishment of these plant communities would restore fish and wildlife populations to some higher numbers (Hoffman et al. 1985). Though most scientists would not disagree with these general assumptions, supporting data are not available for Tampa Bay. More importantly, the direction of restoration efforts should have a sound scientific basis in order to produce measurable results.

Eutrophication

Eutrophication is defined as the process of increasing dissolved nutrient concentrations to a point where nutrient enrichment produces certain characteristic responses in a water body. These responses include algal blooms, noxious odors, declines in dissolved oxygen, and periodic fish kills. Such characteristic responses have been observed in Tampa Bay, particularly Hillsborough Bay, for 20 years prior to the FWPCA (1969) documentation of nutrient enrichment from partially treated sewage discharges as the primary cause.

Subsequently, over $100 million was spent to upgrade the Hookers Point sewage treatment facility from primary to advanced or tertiary treatment. The upgraded plant came on line in 1979. After that, other studies done by the Florida Department of Environmental Regulation, the U.S. Geological Survey, and the City of Tampa concluded that urban runoff from streets and parking lots could contribute up to 25% of the biochemical oxygen demand, 35% of the suspended solids, and 15% of the nitrogen loading to Hillsborough Bay (Garrity, McCann and Murdoch 1985).

An additional aspect of the problem was added by Fanning and Bell (1985) when they suggested that nutrient fluxes from the bay's sediments could be important as sources of nutrients to the water column. These authors illustrated that ammonia (NH_3) in Tampa Bay reached values higher than those found in other studied estuaries. In addition, the ratio of ammonia to total inorganic nitrogen ($NO_3^- + NO_2^- + NH_3$) was quite high (0.84 + 0.12). Although declines in phosphorus concentrations have been documented for the bay, nitrogen concentrations in the water column have remained high (Johannson and Squires, this volume).

Windsor (1985), examining existing water quality data for 28 coastal areas of Florida, found only three in which nutrient enrichment was indicated and definite problems of oxygen depletion were observed: Perdido Bay, Tampa/Hillsborough Bay, and Biscayne Bay.

Lewis et al. (1985) noted that eutrophication leading to microalgal and macroalgal blooms may have contributed to the decline in seagrasses in the bay due to reduction in downwelling light through competition and epiphytic algae loading on seagrass blades. Direct experimental evidence of this has been provided by Twilley, Kemp, Staver, Stevenson and Boynton (1985), where artificial nutrient loading leads to light attenuation by microalgae, epiphytic algae loading on leaves of macrophytes, and significant decreases in biomass of submerged macrophytes. Orth and Moore (1983) hypothesized that the significant loss of submerged aquatic vegetation in Cheseapeake Bay may be due, in part, to similar nutrient enrichment.

Fanning and Bell (1985) recommended that four areas of research be pursued to further clarify the problem of eutrophication in Tampa Bay:

1. Long range coordinated nutrient sampling of the bay to accurately characterize conditions and detect changes;

2. Sampling to determine pathways and rates of nutrient transformation;

3. A study of interactions and exchanges of nutrients between the bay and the Gulf of Mexico; and

4. Clarification of the role of sediments as sinks or sources of nutrients under various conditions.

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HABITAT TRENDS AND FISHERIES IN TAMPA AND SARASOTA BAYS

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Fisheries are an important result of the complex biological web of Tampa and Sarasota Bays. Habitat plays an important critical role in defining the success of any given species within a system. Habitat refers to the specific structural, physical, and chemical environment in which an organism lives. This paper will focus on several components of the estuary considered important to the juvenile populations of commercial and recreational fishery species in Tampa and Sarasota Bays. The discussion on fisheries will provide only an overview of the actual industry and highlight some relatively new programs that will have a long-term influence on fisheries management in the bays. General references to Tampa Bay imply the inclusion of Sarasota Bay unless otherwise stated.

HABITAT TRENDS

Fisheries habitat includes mangrove, saltmarsh, seagrass meadow, intertidal mudflat, and unvegetated subtidal bottom communities. An integral and encompassing habitat component that influences the distribution of other components is the water column. Other less extensive, specific habitats of the Tampa Bay system contribute to the fishery, but they will not be detailed here. Figure 1 defines the boundaries of the quantitative analyses for habitat distribution and trends. The total estuarine area for this region is 124,155 hectares (ha, 1 ha=2.47 acres).

Mangroves cover approximately 8,036 ha, or 7% of the bay estuarine environment. Although Tampa Bay is near the northern limit of their distribution, mangroves remain an important component of the intertidal system. The aerial root systems provide a substratum for algal and invertebrate attachment and serve as a structural and protective habitat for juvenile fish, crustaceans, and shellfish. Leaf litter can also be important, forming the basis of a mangrove-detritus food web and providing a food supply to many organisms and ultimately the fishery. Mangroves also stabilize sediment and can be a nutrient and sediment trap for upland runoff.

Saltmarshes cover approximately 1,432 ha, or 1% of the bay estuarine environment. In Tampa Bay they generally serve as intertidal transition zones between mangroves and the freshwater marsh systems. Marshes also grow in mangrove areas damaged by occasional freezes (Lewis, this report). Like mangroves, saltmarshes provide a concentration of high-quality food for estuarine animals in addition to a protective

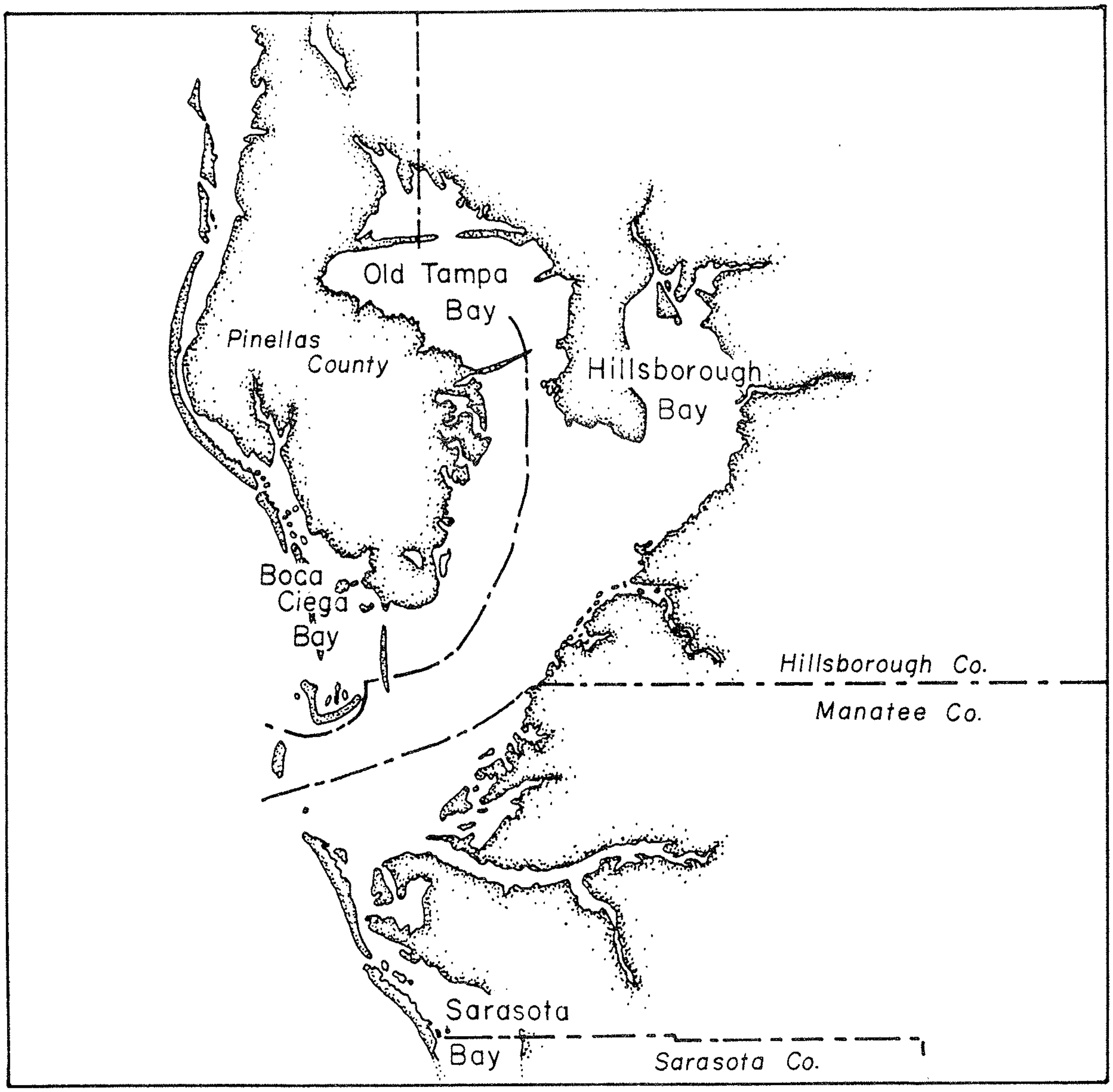


Figure 1. Boundaries for the quantitative analysis of habitat distribution and trends in the Tampa Bay Region.

environment for early life stages. Saltmarshes are also a fundamental part of nutrient cycles, long-term accumulators of pollution, short-term pollution buffers, and inhibitors of erosion.

Seagrass Meadows cover approximately 12,968 ha, or 10% of the bay system. They are the dominant vegetative cover in the bay and are critically important to productivity of the bay system. Seagrass meadows provide a direct food source to herbivores, such as sea turtles and manatees, and to numerous detritivores. Because this habitat is subtidal and extensive in distribution, it provides a constant and expansive structural shelter for fish, shellfish, and crustaceans important to the fishery. In addition, the complex food web and tremendous organism diversity and quantity provide a major food source to all stages of fishery species in the bay. Seagrass meadows also stabilize sediments and prevent erosion. They improve water quality by removing nutrients and by providing a baffle effect on waves and currents, which causes settling of suspended particulates in the water column. Macroalgae, in either drift or attached forms, are often associated with seagrass meadows and other communities of the estuary. The algae are a more readily digestible food source than seagrass and appear to be important to the ecology of the estuary.

Mudflats (sandbars, sandflats, flats) cover approximately 9,389 ha, or 8% of the bay bottom. They are "unvegetated" sites that become exposed at low tide. During the day they serve as primary feeding grounds for wading and shore birds. At night, fish, crabs, and shrimp become major consumers. Production in a mudflat is driven by smaller algae, such as dinoflagellates, diatoms, and blue-greens; macrophytic algae have a lesser role. Flats do not provide a protective structural component except to burrowers. A special type of flat found in Tampa Bay is the saltbarren (saltern), a transitional area between mangrove-saltmarsh and uplands. Although a harsh habitat, saltbarrens are important for bird populations, and growing evidence exists that they support fisheries species during irregular flooding. Saltbarrens host a variety of vegetation from stressed mangroves to lush succulents.

Unvegetated subtidal bottom comprises 92,334 ha, or 74% of the estuary. For this discussion, this area also includes artificial reefs, natural rock reefs, algal communities, sand, mud, and others. This habitat type is a major component of the system, as in most estuaries, and although extremely important for overall bay production, its extent serves to emphasize the importance of the relatively lesser amounts of structural, vegetative cover on the periphery of the bay.

Depending on the tides, the water column, overlies part or all of the estuarine habitat. The chemical, physical, and biological composition of the water column influences all aspects of the estuary. Phytoplankton are the primary producers and not limited to shallow areas or shorelines (as are seagrasses, mangroves, and saltmarshes). Phytoplankton exist as readily digestible food for consumers and are essential components in the food chain that supports larval stages of the fishery. An abnormal abundance of phytoplankton occurs in the Tampa Bay region as a result of an overabundance of dissolved nutrients. This process of eutrophication can have serious implications for the quality of production in the bay.

Through a cooperative study, the U.S. Fish and Wildlife Service (USFWS) and the Florida Department of Natural Resources (FDNR) estimated habitat changes in the Tampa Bay area from the 1950's to 1982. The data, housed in digital form on the DNR Marine Resource Geographic Information System (MRGIS) are photo-interpreted aerial photographs that have been computer digitized in a 1:24000 scale using the National Wetlands Inventory standard classification system. Over 600 separate categories are detailed in this hierarchical classification for the Tampa Bay region. Two 7.5-minute USGS topographic quadrangles (approximately 36,000 ha, northwest and southwest portion of Figure 1) have been interpreted and digitized into the MRGIS in addition to the data developed in conjunction with USFWS. The data have been synthesized on the MRGIS into general categories for ease of discussion (Table 1).

Table 1. Summary of major habitat trends, in hectares, for the Tampa Bay region.

Habitat	1950	1982	Percent Change
Mangrove	8,629	8,032	- 7
Saltmarsh	2,063	1,432	- 30
Seagrass	25,801	12,968	- 50
Mudflats	6,812	9,389	+ 37
Freshwater wetland	18,335	14,440	- 21
Agriculture	25,347	45,193	+ 78
Range/forest	124,630	42,997	- 65
Urban	32,730	95,586	+192

Lewis et al. (1985) estimated that 44% of the saltmarsh and mangrove and 81% of the seagrass meadows have been lost in Tampa Bay since the late 1800's. The recent calculations (Table 1) are not readily comparable because of differences in time, methodology, vegetation classification, and aerial coverage. However, the results confirm that significant losses of habitat have occurred. Perhaps the most significant deviation from other published results is the seemingly small loss of mangroves (7%) in the bay. This is an artifact of the USFWS classification system which underestimates change for this particular category and is being addressed in the MRGIS database.

Significant loss of fishery habitat has occurred in the Tampa Bay area. Loss of marsh and mangrove has been the result of dredge and fill activities. Dredge and fill has caused direct loss of seagrasses and indirect impacts have been hypothesized, primarily from changes in water quality which preclude seagrass growth. Dredge and fill activities are now under strict control; although permitted dredging continues, protective measures exist to minimize loss that is not "for public benefit". Water quality is considered the primary and continuing limit to seagrass distribution in the bay. Loss of seagrass has generally occurred throughout the bay, but the most significant losses have occurred in Boca Ciega Bay and the upper portion of Tampa Bay. In Boca Ciega Bay, shallow seagrass meadows were dredged into massive fill areas for residential and commercial development. Simon (1974), citing other researchers, indicates that loss of Boca Ciega Bay bottom destroyed a standing crop of 1,133 metric tons of seagrass and in annual production; 25,841 metric tons of seagrass; 73 metric tons of fisheries products; and 1,091 metric tons of associated infauna. In 1968, this translated to an estimated value of $160/hectare/year loss, or $1.4 million, annually. Simon (1974) estimated a loss in natural investment by 1974, if capitalized at 6%, of $23 million. Although these values are opinionated estimates, the point to understand is that these are substantial economic losses.

Loss of seagrass in upper Tampa Bay has been caused partially by dredge and fill, but the majority has not been due to direct mechanical destruction. Figure 2 depicts seagrass loss since 1950. In Hillsborough Bay (eastern extension of the upper bay), the loss is 90%. Changes in water quality suspected as the causative factors can be attributed to: 1) loss of range/forest and freshwater and saltwater wetlands,which act as filtering systems for runoff; 2) increases in agricultural area, which may increase sedimentation and suspended particles in the water; 3) intense urbanization and industrialization, which generate wastewater and stormwater disposal problems; and 4) dredging, which causes long-term release of fine sediments into the bay environment. With such large increases in urban and agricultural development (see Table 1) and decreases in those habitats that cleanse and buffer the bay, we can expect imbalances and changes to occur within the system as a whole.

The overall importance of the seagrass community to the region cannot be overstated. For perspective, the Chesapeake Bay estuary encompasses 3,237 sq. mi. and has 75 sq. mi. of seagrass (2% coverage), whereas the Tampa Bay region encompasses 479 sq. mi. and has 50 sq. mi. of seagrass (10% coverage). A major issue in Chesapeake Bay has been the importance of the seagrass meadows to the overall production in the bay. It is readily apparent that this should be a major issue for Tampa Bay.

FISHERIES

The Tampa Bay region has historically been a highly productive source of consumable fish and shellfish. Indian populations used the bay for food and tools. During the 19th century, the bay was a commercial fishing area for boats from as far away as New England (Pizzo, 1968; cf. Lombardo and Lewis, 1985). The first known fishery lost in the bay was the Atlantic sturgeon, with 5,000 lb. landed in 1867 and 6,500 lbs landed in 1868. Sturgeon all but disappeared in 1869, probably due to fishing

LEGEND

Land

Seagrass (1982)

Seagrass-present in 1950
but absent in 1982

Figure 2. Seagrass loss in upper Tampa Bay and Hillsborough Bay.

pressure and poor recruitment; they no longer inhabit the bay. The area remains a fishing center, but fishing is not the primary water-dependent industry. Two counties in the Tampa Bay region --Pinellas and Hillsborough-- ranked 2nd and 6th, respectively, in value of Florida landings in 1976 (Mathis et al., 1979), confirming the importance of the industry even to the present. The 1986 dockside value of the fishery to the region is presented in Table 2 as estimates; the prices used to calculate the values are based on statewide averages and do not reflect local variations.

Table 2. 1986 fisheries landing for the Tampa Bay region including the number of trips made by the fishermen, pounds landed, and value of the fishery at dockside (Kennedy, pers. comm.).

County Landed	Trips	Pounds	Dockside Value $
Pinellas	32,549	10,658,222	$14,275,594
Hillsborough	8,463	8,662,909	5,293,494
Manatee	28,412	15,395,044	4,938,522
Sarasota	5,799	659,400	356,228
TOTAL:	75,223	35,375,575	$24,863,838

Commercial landings have traditionally been used to monitor trends in the fishing industry and economic value. Commercial landings data have historically been collected by the National Marine Fisheries Service (NMFS) and were originally designed to monitor the value of the fishery on a national scale. Landings data have little additional validity other than to observe possible trends in the fishery. NMFS landings data cannot provide the number of man-hours to catch a fish (catch per unit effort), the recreational catch, or where the fish were caught. These put severe limitations on the interpretation of the data, i.e., whether a decline is due to fewer fish, fewer fishermen, low dockside prices, or inclement weather.

Enhanced approaches to fisheries management have been instituted at the state level which will have a positive impact on fisheries management in Tampa Bay. The 1983 Florida Legislature created the Marine Fisheries Information System to gather the types of fisheries data necessary for management and research. FDNR expanded the NMFS commercial landing data collection to create a marine fisheries trip ticket. Florida law requires that anyone wishing to sell their catch of saltwater products must have a valid Saltwater Product License and that licensed wholesale seafood dealers must maintain records of each sale on a coded trip ticket. The data collected are both mandatory and voluntary. The mandatory information includes time fished, county landed, species sold, and number of pounds of each species caught. The voluntary information requested includes area fished, depth where caught, number of traps pulled/days since last pulled, and price per pound. Voluntary reporting has been used for the latter information, because it was felt that these specific types of information would be more reliably reported. Voluntary information has been used to estimate total landing for an area by statistically extrapolating the percent of voluntary "area fished" reports to the landings that did not have this information. Catch per unit effort by area can be determined by comparing the number of trips reported and the time fished with the pounds of each species caught.

The estuarine species listed in Table 3 are indicative of those produced and caught in Tampa Bay. By using the trip ticket information, we can specifically target the bay landings. For example, bait shrimp landings in pounds can be extrapolated to 31,619,800 live individuals. By using "area caught" information (not shown), we can estimate that only about 5,000,000 of those shrimp were caught in Tampa and Sarasota Bays; the remainder were caught north and south of the bay. Eight hundred trips were needed to catch the 5,000,000 shrimp, or 6,250 shrimp/trip worth about 150 dollars to the shrimper.

Table 3. Some typical species caught in the Tampa Bay region in 1986.

Species	Trips	Pounds	Dockside Value $
Bait shrimp	4,341	316,198	$ 692,473
Blue crabs	1,852	198,025	74,690
Clams	54	5,219	24,894
Menhaden	328	5,106,083	255,304
Mullet	12,748	6,842,456	2,253,528
Sheepshead	4,101	100,193	33,063
Spotted seatrout	7,037	175,432	171,923
Oysters	1	103	31

The majority of the remaining species in Table 3 were caught in the bay region. The major fishery in pounds and value is mullet. An Asian market for mullet roe (up to $30/lb retail) was developed in the 1970's and has influenced the value of this fishery tremendously (Figure 3). Fishing pressure has also increased, and research is currently being conducted on mullet populations.

Clam and oyster landings are very low in this area, primarily because only 15-20% of the potential shellfish areas are approved for harvest. The Department of Natural Resources has been systematically closing portions of the bay to shellfishing, because these areas do not meet state and federal water quality standards for shellfishing. Old Tampa Bay was permanently closed in 1979, and portions of the lower bay system have been temporarily closed in the 1980's. Permanent closures are expected to increase with continued urban growth around the bay. Scallops, which require good water quality, disappeared from the bay by

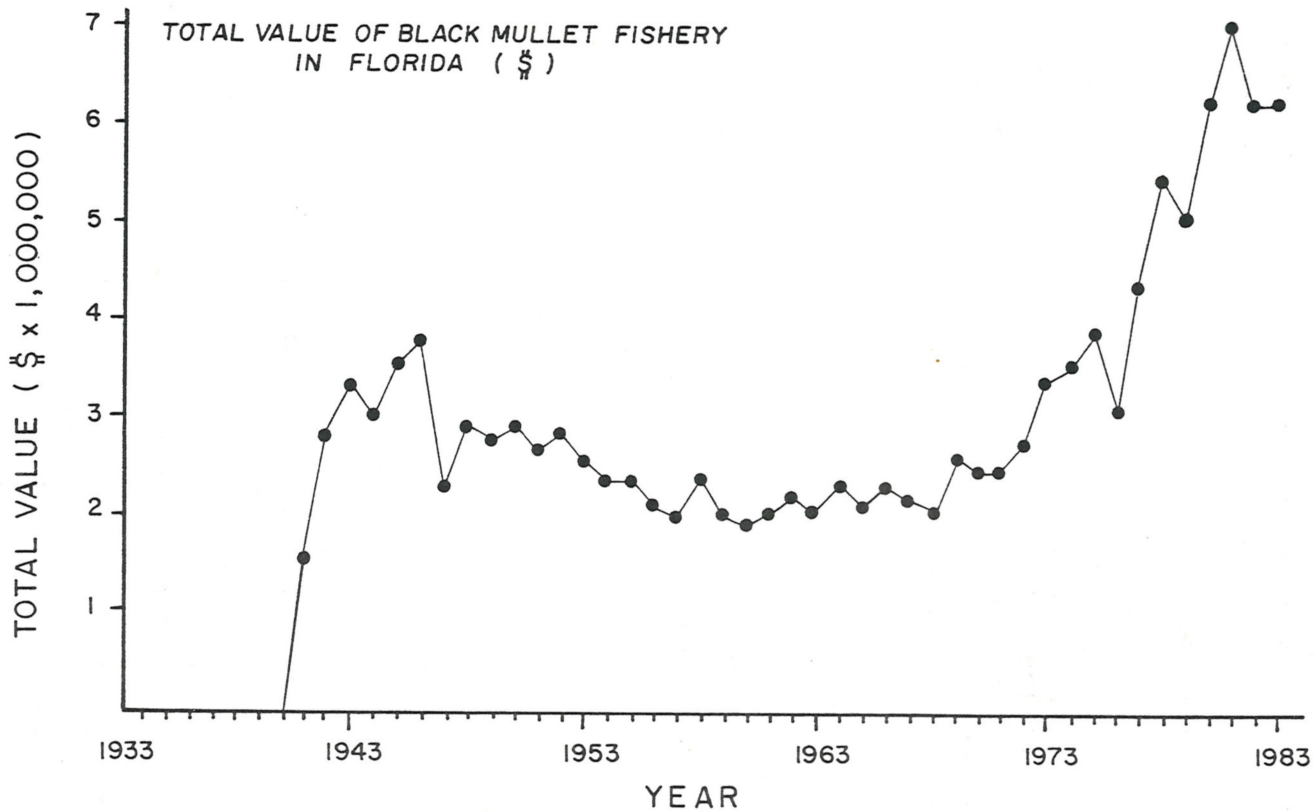


Figure 3. Black mullet fishery value in Tampa Bay, 1940-1983.

1963 (in commercially or recreationally viable numbers) and are only occasionally found today.

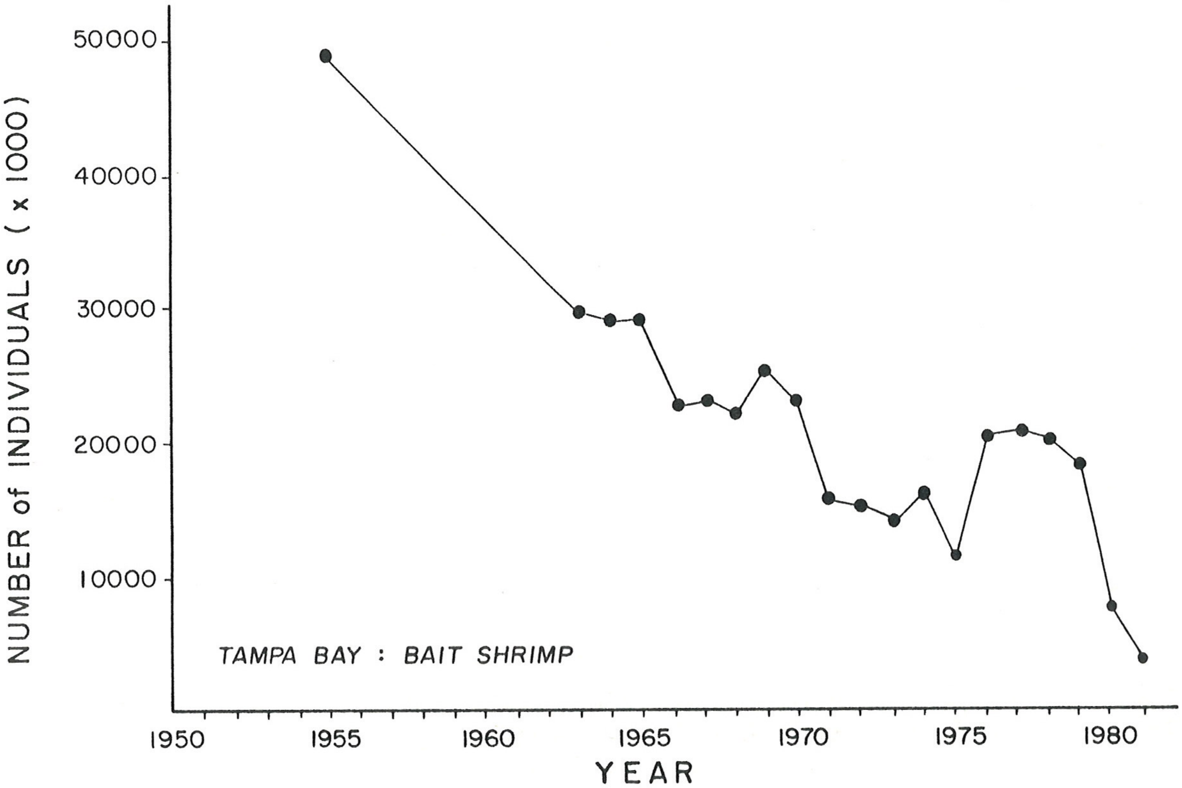
Menhaden are another species actively sought in the bay. The catch was minimal until 1985, when a controversial fishery suddenly developed. The recreational fishermen targeting tarpon have complained that tarpon no longer feed in the bay as they have in the past, because commercial fishermen are catching all of the baitfish, such as menhaden. Some research is currently funded to address the baitfish problem, which in reality can be accomplished only by understanding the entire ecosystem.

Spotted seatrout landings further demonstrate the utility of the marine fisheries trip ticket information. Of the 175,000 lbs landed, 157,000 lbs were from the bay system. Of the 7,655 trips reporting trout, only 278 landed more than 100 lbs, suggesting that trout are an incidental catch. In fact, the primary catch is mullet. Of the 278 trips that apparently targeted seatrout, 111 trips were in January when trout can be concentrated in schools.

The value of this type of information cannot be overstated. It provides a tool for management that has never before been available and does not exist elsewhere in the southeastern region of the country. Recreational catch records are also critically important in complementing the commercial fisheries statistics now being collected. Recreational data are currently collected by NMFS, but they do not have enough regional and local statistical validity to correlate with the trip ticket data. Unfortunately, these data remain a much needed informational component in the Tampa Bay region.

Historical NMFS commercial landings can be compiled to observe potential trends in individual fisheries. Keeping the limitations of the NMFS data in mind, landings for spotted seatrout, _Cynoscion nebulosus_, and bait shrimp, _Panaeus duorarum_, are presented in Figure 4. Declines in catch are consistent and significant and should be cause for alarm.

Spotted seatrout have historically comprised an important recreational and commercial fishery in the Tampa Bay region. Scientific data documenting the reasons for decline in this species do not exist, but we can speculate based on existing knowledge of the juveniles and adults in the Tampa Bay system. McMichael and Peters (in preparation) found that seagrass meadows in Tampa Bay appear to be the primary nursery ground for juvenile seatrout. Seventy-eight percent of 1,379 juveniles collected were found in seagrass, though less than 40% of the collections were made in this habitat. Furthermore, commercial and recreational fishermen target seagrass meadows as the most likely source of adult spotted seatrout. Seatrout are non-migratory, spending their entire life cycle in a given estuary, and thus the Tampa Bay region can be assumed to produce and support its own population with minimal external influences. Although numerous factors control the spotted seatrout population, a loss of 50-80% of the seagrasses in Tampa Bay should affect landings. We may also assume that with the loss of seagrasses, the actual production



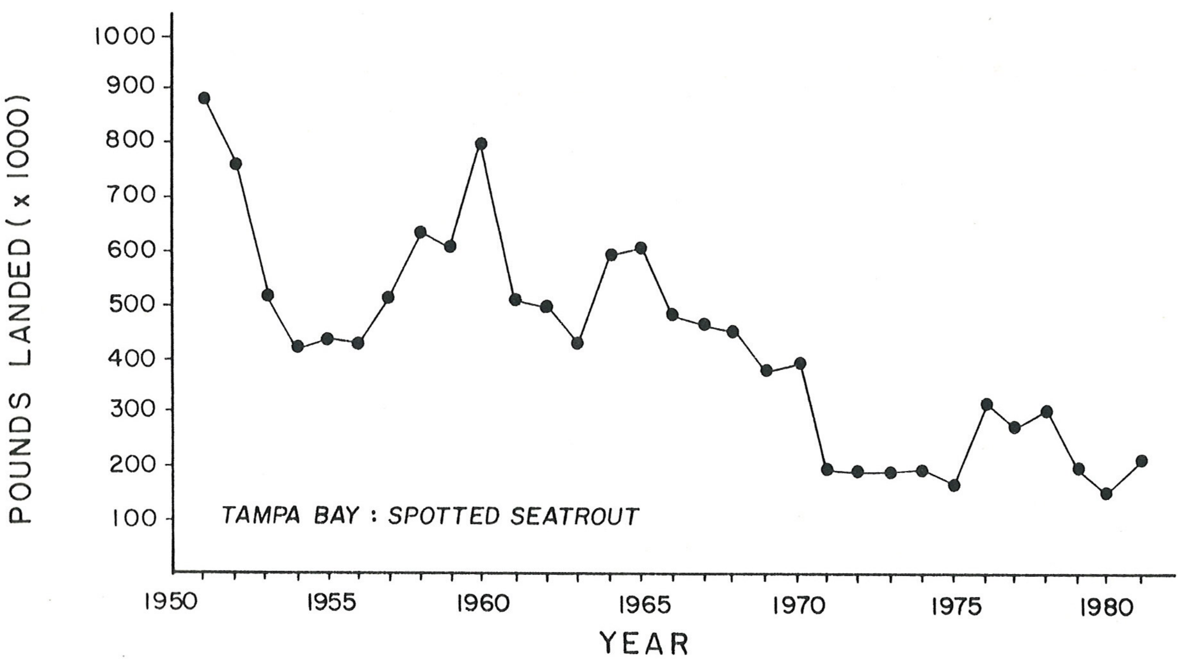


Figure 4. Landings of bait shrimp (top) and spotted seatrout (bottom) in Tampa Bay.

potential (carrying capacity) of this species would be reduced in the bay, and the seatrout population could not recover to historical levels, even if all fishing pressures were eliminated.

The bait shrimp industry also relies heavily on production in seagrass meadows. Bait shrimp are kept alive and sold in the retail market to recreational fishermen. The shrimp are captured by roller-trawls specifically designed to work efficiently in seagrass meadow target areas. Unlike seatrout, adult shrimp migrate offshore to spawn, and the juveniles return to use the seagrasses, marshes, and mangroves as nursery grounds. Again, the loss of seagrass can be expected to influence the catch of bait shrimp and their population potential.

The two species just described are representative of many commercial and recreational species caught in Tampa and Sarasota Bays. Over 70% of the commercial and recreational species caught in Florida utilize the estuaries during some portion of their lifecycles, suggesting that we must understand the estuary as a system in order to manage the fishery. Each estuary has unique characteristics that separate it from others that may be reflected in the fishery. For example, biologists have found that the primary nursery ground for red drum (redfish, *Sciaenops ocellatus*) in some Texas estuaries appears to be seagrass meadows (Holt et al., 1983), whereas Peters and McMichael (1987) determined that primary nursery areas in Tampa Bay are quiet backwaters with freshwater influences. The red drum in Texas spawn offshore; the Tampa Bay red drum spawn at or near the entrance to the bay. These findings suggest that specific studies in individual estuaries may not apply uniformly to other estuaries which have different physical, chemical, and biological characteristics. We must understand Tampa Bay as a system and conduct appropriate, systematic research to elucidate the information required for effective fisheries management.

The landings data report only adult populations. Juvenile populations can be assumed to have a great influence on the size of the adult populations. Influences on the juvenile populations, such as habitat availability, climatic cycles, spawning success, species competition, and a myriad of other factors, should translate into the potential production of a fishery. Unfortunately, most fisheries research has not concentrated on understanding the quantifiable relationships within an ecosystem. Years of catch-up research must be conducted in order to develop population projection capabilities that can be effectively used in fisheries management.

Research is being conducted in Tampa Bay to develop techniques for assessing juvenile populations of commercially and recreationally important species prior to their entry into the fishery. We expect that relationships between relative abundance of a juvenile population and commercial and recreational landings of adults will provide a tool for projecting the fishery in advance. The fishery can then be managed according to the resource available. This long-term program is linked with research to determine habitat carrying capacities and production potential. The research is being carried out with funding or cooperation from the National Oceanic and Atmospheric Administration Office of Ocean and Coastal Resource Management, National Marine Fisheries Service, U.S. Fish and Wildlife Service, Florida Department of Environmental Regulation, and the Florida Department of Natural Resources.

Only through cooperative federal, state, and local programs and research can the fishery in Tampa and Sarasota Bays be understood and managed effectively. For further information on fisheries programs, contact Frank S. Kennedy, FDNR Bureau of Marine Research, 100 8th Ave. SE, St. Petersburg, FL 33701.

RESTORATION

One logical approach to revitalizing the bay and ultimately the fishery is to enhance the existing habitat. Restoration projects are not new to the Tampa Bay region. They have generally been coupled with mitigation of permitted habitat destruction or small independently sponsored projects. No overall systematic approach has been taken to monitor and evaluate the results of restoration.

In 1985, the Department of Natural Resources developed a legislatively-mandated Marine Habitat Restoration and Research Program, focusing on the restoration of natural vegetative components of marine fisheries habitat (saltmarsh, mangrove, and seagrass). The program was facilitated by commercial mullet fishermen who sponsored legislation requiring a $300 per annum County Gill-Net License. The legislation targeted the Tampa Bay region and overcame the major obstacle to implementing a marine habitat restoration program -- lack of funding. To date, four counties in Florida have adopted this legislation, providing the local initiative critical to the recovery of the bay: Pinellas (1983); Manatee (1984); Hillsborough (1987); and Pasco (1984). All of these counties are in the Tampa Bay region, and the first three encompass Tampa and Sarasota Bays. Revenues over $100,000 per year are administered by the Florida Department of Natural Resources and are legislatively mandated to be used for "marine habitat restoration and research". In addition, local state legislators have provided seed money for specific restoration research on seagrasses, but these funds are not on a continuing basis, such as the county net bill funds.

The Tampa Bay restoration projects have been designed to facilitate significant contributions toward understanding the dynamics of habitat restoration and resource recovery. Without valid project design, results from one project cannot be transferred to another, a factor often overlooked by those seeking comprehensive planning solutions to complex environmental problems.

Activities in 1986-87 have involved transplanting of saltmarsh, mangroves, and seagrass at several sites in the bay. Some experimental plots have been monitored only for survival and growth, whereas other experiment sites are intensively monitored for planting unit survival and spread, water column chemistry (seagrass), and faunal utilization. Monitoring will continue at experimental sites for a minimum of three years while site selection continues for future saltmarsh and seagrass plantings.

Success is not guaranteed in restoring natural vegetation. Factors controlling planting success may be site specific and vary with planting stock sources and handling. Survival of planting units thus far have ranged from zero to 100%. Seagrass restoration is proving to be the most difficult to accomplish, as losses have been extensive and appear to be related to changes in water quality. Until basic water quality relationships with seagrass are understood and addressed, large scale restoration cannot be accomplished. Unfortunately, funds are more easily made available for replanting, and the needed basic research is often overlooked.

The principal interest of this program is in restoration of the complex functions of marine fisheries habitat, which presumably begins with revegetation. Utilization of those habitats created by fisheries organisms, although costly to assess, will provide a perspective on the value of created vs. natural environs. Before large-scale restoration of the Tampa Bay area can begin, planting techniques, survival of plantings, and habitat contributions must be understood. This information is essential to the long-term management of our coastal resources and marine fisheries. The FDNR is being assisted in this work by the NMFS; Mote Marine Laboratory; Pinellas, Hillsborough, Manatee, and Pasco Counties; Pinellas Marine Institute; Mangrove Systems, Inc.; and other contracted and volunteer organizations. The Tampa Bay region has provided the initiative and funding for this effort and demonstrates that difficult tasks may be accomplished by local, state, and federal interactions. For more information on restoration research, contact Alan Huff, FDNR Bureau of Marine Research, 100 8th Avenue SE, St. Petersburg, FL 33701.

STOCK ENHANCEMENT

Stock enhancement is another approach to fisheries restoration. The practice entails hatching, rearing, and releasing fish into the natural environment to augment or enhance target species populations. Stocking of freshwater fishes into lakes, reservoirs, and streams for a management tool and/or for a put-and-take fishery is common. Stocking of fingerling marine fish into estuaries is a relatively untried concept. Stock enhancement in Florida is currently in pilot stages without production hatcheries. The principal hatchery research participants are the University of Miami Experimental Fish Hatchery, Miami; Mote Marine Laboratory, Sarasota; Harbor Branch Foundation, Indrio; and FDNR Bureau of Marine Research, St. Petersburg. The state is constructing an experimental hatchery in Manatee County adjacent to Tampa Bay, on property provided by the Manatee Port Authority. This facility will be the center for research on hatching, rearing, and stocking of red drum, snook, and other species.

Success in stocking marine fishes depends on species chosen, size of fish released (smaller sizes are more susceptible to predation and environmental stress), and habitat carrying capacity (how many juveniles or adults can be supported per acre regardless of the number of fish released). Also, from a hatchery perspective, bio-energenics, growth, metabolism, osmotic/ionic systems, reproductive physiology, feeding dynamics, behavior, and genetics have not been thoroughly investigated (if at all) for most estuarine species.

There are many questions that need to be answered before full-scale stocking, if feasible, can be accomplished. The problems are multi-disciplinary and will require a myriad of information to accomplish an environmentally sound enhancement program. The fisheries and habitat research already discussed will greatly enhance the information base of the stock enhancement program. The Tampa Bay region is fortunate to have this program centered here because of the existing related programs and the demonstrated ability of the scientific and management community to work together. For further information on stock enhancement research, contact Daniel Roberts, FDNR Bureau of Marine Research, 100 8th Avenue SE, St. Petersburg, FL 33701.

SUMMARY

I have briefly addressed fisheries habitat concerns and trends, fisheries management and research needs, habitat restoration, and stock enhancement in Tampa and Sarasota Bays. The complexities of the research have been presented only as an overview. It is important to recognize the cooperative spirit demonstrated by researchers and managers in addressing the problems within this estuary.

Much of the habitat necessary for the maintenance of quality biological production in the bay has been altered. New approaches to fisheries management are being implemented, which should provide enhanced techniques for quantitatively understanding the fishery populations in the bay. Restoration and stock enhancement programs may help to increase the quality of production in the bay. Funding continues to be a prime concern for research and management, but, because of the spirit of cooperation in the bay area, much has been accomplished with minimal dollars. Most programs are minimally funded and need to be put on accelerated schedules. Unless long-term committed sources of funding are directed to the bay area, little improvement in the bay system can be expected in the next decade.

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SURFACE SEDIMENTS AND THEIR RELATIONSHIP TO WATER QUALITY IN HILLSBOROUGH BAY, A HIGHLY IMPACTED SUBDIVISION OF TAMPA BAY, FLORIDA

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Tampa, Florida

INTRODUCTION

Hillsborough Bay is the subdivision of Tampa Bay that has received the heaviest industrial and municipal impacts associated with the recent urbanization of the Tampa Bay area. Eutrophication of bay waters caused by urban runoff, municipal sewage and industrial discharges, may have contributed to a large area of muddy high organic sediments in Hillsborough Bay. The upper 20cm of the sediment layer, with its associated biota, is an important link in the coupling between the benthic and pelagic communities in this shallow estuarine system. A eutrophic system like Hillsborough Bay supports a large crop of primary producers, mostly phytoplankton, which produce more organic matter than can be utilized by the primary consumers. Surplus organic matter and waste material from consumers settle to the bottom creating sediments of high organic content. Effluents and runoff contribute additional organic matter to natural background levels. Organic matter in the sediment is mineralized and nutrients are released to the water column where they become available for planktonic primary production. The metabolic processes associated with the benthos create an oxygen demand which may reduce oxygen in the overlying waters. Reduced oxygen concentrations can have a drastic impact on the estuarine community structure through large scale die-offs of the benthic and pelagic fauna. Benthic nutrient regeneration and the related process of dentrification are important in the recycling and availability of nutrients in estuaries. In Hillsborough Bay, however, few specifics are known of rates and pathways of these important links between the benthic and pelagic systems.

This paper will summarize the composition of surface sediment and sediment oxygen demand rates in Hillsborough Bay. Also, a first attempt is made to relate the nutrients released from these sediments to the phytoplankton, the dominant primary producers of the bay. Much more work is needed to understand better how the sediments and their biota affect water quality in Hillsborough Bay.

TAMPA AND HILLSBOROUGH BAY SURFACE SEDIMENT STUDIES

In Tampa Bay, including Hillsborough Bay, several studies of surface sediment composition and distribution have been conducted since the 1950's.

Goodell and Gorsline (1961) analyzed surface sediments for grain size, carbonates and organic carbon from all major areas of Tampa Bay including approximately 30 stations in Hillsborough Bay. They concluded that Tampa Bay sediments are a mixture of eroded quartz sands from Pleistocene terrace deposits and carbonates from mollusk shell fragments produced within the system. The present sediment distribution is attributed to tide generated currents. In general, sediment grain size increases toward the mouth of Tampa Bay and fine high organic material is found in the upper reaches of Hillsborough Bay and isolated areas of Old Tampa Bay.

The surface sediments of Hillsborough Bay were studied intensively in 1968 by the Federal Water Pollution Control Administration (FWPCA 1969). This study was conducted in cooperation with local authorities to suggest ways to improve the poor water quality of Hillsborough Bay. Ninety-five surface sediment samples throughout Hillsborough Bay were collected and analyzed for organic carbon, nitrogen and phosphate. A large area of the bay bottom (16%) contained sediments with a high organic carbon content of at least 3% of sediment dry weight. Highest organic carbon sediment concentrations were associated with discharge points from sewage treatment plants, river mouths, and areas deeper than ten feet with weak tidal currents. The most important sources of high organic mud were thought to be the Hillsborough and Alafia Rivers, the Hooker's Point primary treatment plant, and the decomposition of settled phytoplankton. The nitrogen content of the sediments followed the distribution pattern of organic carbon, while sediment phosphate concentrations were highest near the mouth of the Alafia River (Flannery, this report). The historically low dissolved oxygen concentrations found in deeper waters were attributed to high benthic oxygen demands of muddy high organic sediments. The FWPCA (1969) recommended selective dredging of the extensive high organic deposits to improve Hillsborough Bay water quality. The recommended dredging has not been performed to this date.

Taylor and Saloman (1969) collected surface sediments between 1961 and 1965 from 773 locations in Tampa Bay and the adjacent Gulf of Mexico. Samples were analyzed for grain size composition, calcium carbonate content, and concentrations of organic carbon and organic nitrogen. Although much of Taylor and Saloman's (1969) data remain uninterpreted, Taylor, Hall and Saloman (1970) used the data to relate sediment composition to mollusk abundance and diversity at 45 locations in Hillsborough Bay. Most deep stations had silty sediments and lacked mollusks. Areas lacking mollusks, which included several shallow sandy stations, were classified as unhealthy. Unhealthy areas were located along the eastern and western shores of the bay and near the mid-bay shipping channel. Healthy areas were found at the mouth of Hillsborough Bay and in McKay Bay. Unhealthy areas comprised 42% of the bay bottom and only 22% of the bottom was considered healthy.

Doyle, Van Vleet, Sackett, Blake and Brooks (1985) analyzed sediment grain size composition and hydrocarbon concentration and distribution in Tampa Bay surface sediments during 1984 and 1985. Their conclusions concerning sediment distribution and composition were similar to those of Goodell and Gorsline (1961). Doyle et al. (1985) suggested that fine grained material dominating Hillsborough Bay surface sediments is derived from rivers and urban runoff. In situ generation of fine, high organic material produced by the flora and fauna within Hillsborough Bay was not discussed. Potential areas of widespread hydrocarbon contamination were found in upper Hillsborough Bay and the lower portion of the Hillsborough River. The rest of Tampa Bay appears relatively uncontaminated.

During the summer of 1986, the Florida Department of Environmental Regulation (in cooperation with Science Applications International Corp.) photographed the surface sediments in Hillsborough Bay from May 28 to June 2, 1986 (SAIC 1987). A vessel-deployed sediment profile camera was used at 200 locations with water depths greater than 2m. Results from the report were based solely on computer image analysis of the profile photographs, referred to as REMOTS technology. No traditional sampling methods were utilized. A series of quantitative and qualitative sediment characteristics and processes, including the distribution of successional stages of benthic macro-invertebrates were mapped from the photographs. The report stated that several kinetic regimes influence the sediment pattern in Hillsborough Bay. The shallow areas which are subject to scouring have well-sorted sandy sediments, while low kinetic deep areas in the central axis of the bay have mostly silt-clay size sediments. The REMOTS study also documented apparent high sediment oxygen demand (SOD) areas where seasonal hypoxia could be expected during the warm months. SAIC (1987) recommended long-term monitoring of potentially anoxic areas to determine impacts from anthropogenic pollution and overall "health" of the bay ecosystem. Several areas were identified along the margin of the 2m depth contour of Hillsborough Bay which may be degraded by inputs of pollutants, mainly stormwater run-off and sewage discharges, including a large region south of the Hillsborough River, most of the eastern margin of the bay, and two local areas off the Interbay Peninsula.

SAIC (1987) concluded that all hypoxic areas in Hillsborough Bay are located relatively close to shore near point and non-point sources, and that the deeper areas generally lack organic loading and hypoxia. The study suggested that intrusion of cool oxygenated bottom water from lower Tampa Bay may keep the deeper parts of Hillsborough Bay aerobic. SAIC (1987) also postulated that bioturbation from the high-order successional stage benthic invertebrates living in the deep areas stimulate microbial activity, which in turn, prevent the build-up of labile organic matter. The last macro-benthic study in Hillsborough Bay was conducted from 1975 to 1978 (see Santos and Simon 1980). A comprehensive study is presently needed to establish the current macro-benthic environment and to evaluate SAIC's (1987) findings.

CITY OF TAMPA INVESTIGATIONS OF HILLSBOROUGH BAY SEDIMENTS

FDER Wasteload Allocation

In 1981, the Florida Legislature repealed a statue requiring advanced wastewater treatment (AWT) for domestic wastewater treatment facilities constructed after 1972. The statue was replaced by a mandate requiring the Florida Department of Environmental Regulations (FDER) to specify wasteload allocations on a case-by-case basis for domestic point sources. The FDER began a "wasteload allocation" study to evaluate the dissolved oxygen and nutrient impacts of Tampa Bay (including Hillsborough Bay) surface water dischargers for long-term wastewater planning and permitting. A "wasteload allocation" draft report (McClelland 1984) was released by FDER in 1984 for review by interested parties. Several criticisms of that draft report were communicated to FDER by individuals of the local scientific community and the Tampa Bay Management Study Commission (Tampa Bay Management Study Commission 1985). One major criticism was that the contribution of sediment pollution sources was based on insufficient data.

The City of Tampa (COT) operates an advanced wastewater treatment plant with a permitted discharge into Hillsborough Bay of 60 mgd. It was in the interest of the COT to cooperate with FDER in obtaining the most accurate data for their wasteload allocation study. The Bay Study Group (BSG) of the COT Sanitary Sewer Department, in agreement with the FDER, launched a two phased sediment project in Hillsborough Bay to, (1), map the surface sediment composition, and (2), quantify dissolved nutrient fluxes between the water column and sediments through *in situ* measurements of sediment oxygen demand (SOD) rates and nutrient exchange rates (NERs). Detailed results of the BSG sediment project have been submitted to the FDER in two reports (COT 1986a, 1986b).

Distribution and Description of Hillsborough Bay Surface Sediments

Phase 1 of the BSG's sediment project produced a map of Hillsborough Bay identifying areas of "sandy" and "muddy" sediments, and estimated the areal coverage of those sediment types. Continuous depth recording soundings (200KHz transducer) along 29 transects were used in conjunction with sediment grain size analyses from 19 stations to produce a sediment map. "Mud" was assumed to occur at locations where 50% or more (by weight) of sediment particles passed through a 63um mesh sieve. "Sand" occurred where less than 50% of sediment particles (by weight) passed through a 63um mesh sieve. Grain size analyses revealed that sediment compositions, depending on location, ranged from 95.3% "sand" to 98.9% "mud."

"Mud" sections along the 29 transects were interconnected based on bottom topography and dredging information, thereby producing the map shown in Figure 1. The largest expanse of "mud" covered the deeper zones of west-central Hillsborough Bay. The BSG concluded the areal coverage of "mud" constituted approximately 24% of the bottom of Hillsborough Bay.

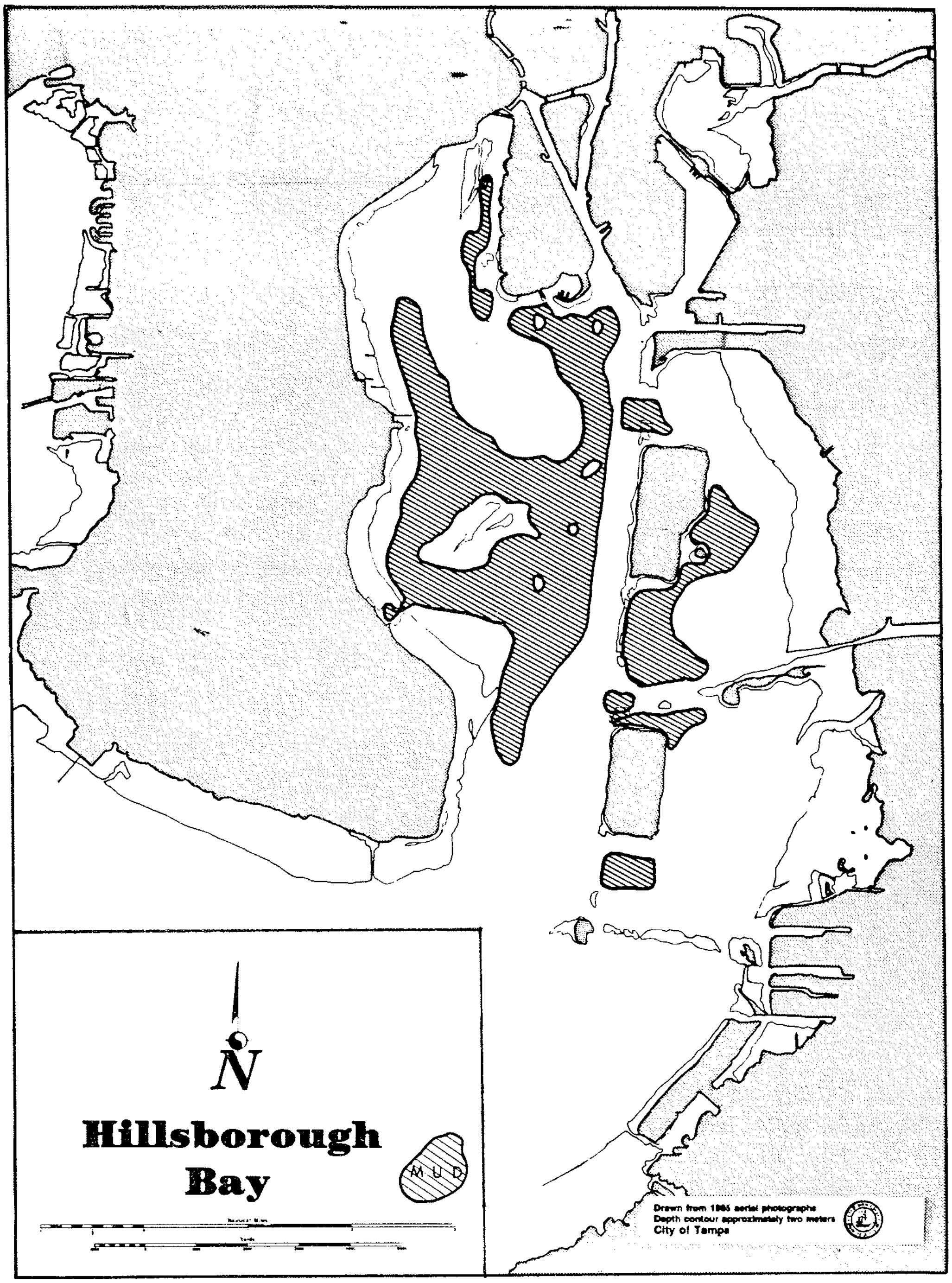

Figure 1. Estimated areal coverage of "mud" in the surface sediments of Hillsborough Bay (modified from COT 1986a).

Thirty years ago, according to grain size contour maps created by Goodell and Gorsline (1961), roughly 32% of Hillsborough Bay surface sediments were fine grained sediments (mean phi >4). Because they did not intend to map fine grained sediments specifically, the areal coverage of these sediments was not as well defined as the "mud" areas delineated by the BSG (COT 1986a). The disparity of mapping techniques used by Goodell and Gorsline (1961) and the BSG prevent any conclusions as to the increase or decrease of fine sediments in Hillsborough Bay during the past 30 years. However, it is apparent that relatively large areas of fine grained surface sediments also existed 30 years ago.

A representative cross section of Hillsborough Bay sediment types was provided by combining subtidal sediment data from the BSG sediment mapping effort with intertidal sediment data from another BSG project (COT 1988). For descriptive purposes, sediment types were partitioned into four groups based on percent sand composition. The sediment groups listed in Table 1 are shallow sand, deep sand, intermediate and soft.

Table 1. Results of grain size and carbon analyses of major sediment types in Hillsborough Bay.

	Shallow Sand	Deep Sand	Intermed.	Soft
% Sand	98-100	82-91	34-64	1-16
% Silt	0-2	3-7	11-35	24-39
% Clay	0-1	6-11	21-34	51-75
Mean phi	2.4-3.0	2.9-3.5	4.5-5.9	6.8-7.9
SD Mean phi	0.4-0.8	1.8-2.0	2.2-2.6	1.2-2.4
% Total Carbon	1-7	5-9	18-37	35-56
% Organic Carbon	0-3	1-3	6-10	15-17

Shallow sand samples were composed almost entirely of well sorted fine quartz sand with a mean grain size of 2.62 phi. Shallow sands occur on intertidal and shallow subtidal flats usually at depths less than six feet and encompass about 20% of the total bay bottom area. Important depositional forces include tides and waves generated by wind and ship traffic. Although most areas lack vegetation, some have macroalgae or sparse seagrass coverage. Microscopically examined, these sediments appear as light colored sand grains intermixed with dark brown invertebrate fecal pellets.

Deep sand samples contained between 83 and 91% of well sorted very fine sands with a mean grain size of 3.16 phi. These sediments occur in subtidal zones at estimated depths of six to ten feet and cover roughly

40 to 45% of the bay bottom. Tidal currents and waves are the major depositional forces. These sediments often contain benthic assemblages of tunicates and tube dwelling amphipods and polychaetes.

Intermediate sediment samples contained between 34 and 64% of fine sands plus a relatively large fraction of clay and silt. They had a mean grain size of 5.17 phi, may occur at depths ranging from 8 to 12 feet, and cover 15 to 25% of the bay bottom. These sediments contain faunal assemblages similar to those found in deep sand sediments.

Soft sediment samples contained primarily clay and silt (92%), with a mean grain size of 7.20 phi. Soft sediments generally occur at depths greater than 12 feet and occupy an estimated 15 to 20% of the bay bottom. Tidal currents and waves exert relatively weak forces at depths greater than 12 ft and so, allows considerable deposition of clay and silt-sized material. Dense mats of amphipod feeding tubes are commonly observed in some areas. These dense mats can inhibit sediment resuspension and may increase the settling rate of suspended particles by acting as baffles (Rhoads and Germano 1986). In other areas lacking macro-benthic organisms, soft sediments coated with a thin light colored sediment layer have been observed (SAIC 1987). The layer contains high concentrations of invertebrate fecal pellets and viable phytoplankton cells. This surface sediment layer can easily be resuspended and represents a highly nutritive energy source for benthic organisms including bacteria.

The organic carbon fraction of total carbon was relatively constant, comprising from one-fourth to one-third of the total carbon measured in each sediment type. The percents of total and organic carbon increased proportionally with increasing percents of mud (% silt + % clay) in Hillsborough Bay sediment samples (Table 1). Shallow sand sediments were low in both total and organic carbon. Invertebrate fecal pellets may be the principal organic carbon source in shallow sands. In contrast, soft sediments were high in total and organic carbon.

Surface Sediment and Water Column Interactions

Phase II of the BSG's sediment project involved the quantification of the oxygen demand and nutrient contributions that Hillsborough Bay sediments have on the overlying water column. Nixon (1981) has shown that a large fraction of the organic matter consumed by the benthos is associated with a significant flux of inorganic nutrients into the water column.

The BSG made in situ measurements of SODs and NERs in Hillsborough Bay during 1986. The SOD chambers and the field procedures employed were the same as described by Murphy and Hicks (1985)[1]. Nutrients were

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[1] Nutrients were analyzed by the Hillsborough County Environmental Protection Commission.

analyzed by the Environmental Protection Commission of Hillsborough County. Experiments in "sandy" and "muddy" sediments were performed during a winter and a summer month. "Mud" and "sand" locations, as previously defined in phase I, contained 85% "mud" (mean phi 6.9) and 88% "sand" (mean phi 3.1), respectively. The SOD and NER results in Table 2 may be the best available for Hillsborough Bay, but due to the paucity of measurements, these results should be considered as initial estimates with room for refinement. The highest SOD rate occurred during the summer at the "muddy" high organic sediment location and that value was roughly twice the rates of all other season-sediment combinations. These preliminary results also indicate that sediment releases of inorganic phosphate and ammonia were greatest during the summer, and therefore may be a function of temperature. Nixon, Oviatt and Hale (1976) related benthic ammonia fluxes to bottom water temperatures between 0 and 25°C by the equation:

(1) $dc/dt\ (NH_4) = e^{0.16T+1.90}$

where T = temperature in degrees Celcius.

We calculated flux rates (uM $m^{-2}h^{-1}$) using this equation with Table 2 data. The predicted (119) and measured (116) flux rates for winter data at 18°C were in close agreement. However, the average measured summer flux rate (485) was only half the predicted rate (880) at 30.5°C indicating that Nixon et al.'s (1976) function may not apply at temperatures above 25°C.

Table 2. Sediment oxygen demand (SOD, mmoles O_2 $m^{-2}h^{-1}$) and nutrient exchange rate (NER, umoles $m^{-2}h^{-1}$) estimates in Hillsborough Bay during 1986. The negative value indicates a decrease in water column concentration with time, consequently, a meaningful N:P ratio for mud during the winter could not be calculated.

	WINTER		SUMMER	
Parameter	Sand	Mud	Sand	Mud
SOD	8.8	5.6	8.1	14
NER (PO_4-P)	10	-23	137	104
NER (NH_3-N)	111	121	396	573
N:P ratio	11	--	2.9	5.5

The relatively low N:P ratios of inorganic nutrient fluxes from the sediments (Table 2), particularly during the summer, may reflect the importance of bacterial dentrification in the sediments. Assuming that deposited organic material is mostly derived from phytoplankton, then the Redfield N:P ratio of 16:1 might be expected in the regenerated nutrient supply. Low N:P ratios measured in benthic nutrient fluxes to the water column in several shallow marine environments have been attributed to a loss of nitrogen as N_2 from the system by bacterial denitrification (Nixon 1981). Natural assemblages of Hillsborough Bay phytoplankton grown in chemostat cultures were often found to be nitrogen limited (COT 1983). Consequently, the rate of denitrification could influence the supply of nitrogen available to support primary productivity.

The rate of organic matter consumption by Hillsborough Bay sediments, in terms of SOD rates, are within the range of rates measured in other Tampa Bay embayments as well as other U.S. east coast estuaries (Table 3). Annual benthic ammonia flux from Hillsborough Bay sediments into the water column were slightly higher relative to other U.S. east coast estuarine sediment releases (Table 4). As a growing number of *in situ* benthic flux measurements are generated, there appears to be a relationship between the amount of organic matter consumed and inorganic matter released by the benthos in terms of ammonia. Nixon (1981) found a positive relationship between summer rates of sediment oxygen uptake and ammonia release for temperate coastal marine systems with widely ranging phytoplankton productivity levels. Rate measurements of those marine systems ranged from about 2 to 8 mmoles $O_2 m^{-2}h^{-1}$ uptake and 25 to 500 umoles $m^{-2}h^{-1}$ ammonia released. Hillsborough Bay falls in the upper ranges of those rates (11 O_2; 485 ammonia) when the summer data (COT 1986b) are averaged. The relatively high rates in Hillsborough Bay, a subtropical estuary, may simply be due to higher temperature.

Table 3. *In situ* sediment oxygen demand (SOD) rate measurements (mmoles O_2 $m^{-2}h^{-1}$) and water temperatures (^{0}C) during experiments from selected U.S. east coast estuaries and Tampa Bay area estuarine embayments.

Water Body	Temp	SOD	Source
Patuxent River Estuary	24-31	11.8-19.3	Boynton et al., 1981
Patuxent River Estuary	3-29	1.3-10.7	Boynton et al., 1980
Narragansett Bay	3-21	0.6-9.4	Nixon et al., 1976
Chesapeake Bay	Aug-May	3.9-8.1	Boynton & Kemp, 1985
N. Carolina Estuaries	1-22	0.8-3.2	Fisher et al., 1982
Tampa Bay Area:			
Hillsborough Bay	17-31	5.6-14.4	COT, 1986b
Hillsborough Bay	16-30	2.1-8.2	Murphy & Hicks, 1985
Tampa Bay	31	6.9-12.7	Murphy & Hicks, 1985
Sarasota Bay	20-30	4.8-14.2	Murphy & Hicks, 1985

Table 4. Mean annual (time weighted) flux rates (umoles $m^{-2}h^{-1}$) of ammonia-nitrogen from selected U.S. east coast estuarine sediments.

Water Body	Temp	SOD	Source
Hillsborough Bay	111-573	300	COT, 1986b
Patuxent Estuary	0-1584	295	Boynton et al., 1980
Neuse River Estuary	71-454	224*	Fisher et al., 1982
South River Estuary, NC	0-267	113*	Fisher et al., 1982
Narragansett Bay	0-400	100	Nixon et al., 1976
Buzzards Bay	2-124	68	Rowe et al., 1975

*Mean value (not an annual time-weighted average).

The importance of Hillsborough Bay sediment nutrient fluxes can be assessed relative to the nutrient demands of water column primary production. Annual Hillsborough Bay phytoplankton production is 620 $gCm^{-2}yr^{-1}$ based on ^{14}C measurements from 1978 to 1983 (Johansson, Steidinger and Carpenter 1985). Water column demands were estimated assuming that phytoplankton production accounts for nearly all primary production and that phytoplankton assimilate N and P in proportion to the Redfield C:N:P ratios of 106:16:1. Selected Hillsborough Bay ammonia and orthophosphate inputs expressed as a percent of N and P assimilated by phytoplankton are shown in Table 5. The sediments can support 34 and 140% of the phytoplankton N and P demand, respectively. The Alafia River, a major source of dissolved material to the bay, can only supply 0.3 and 51% of N and P demand, respectively. The COT advanced wastewater treatment plant, often cited as a major point source of nutrients, can only supply a small fraction of the N demand and 25% of the P demand if no other sources were available.

Table 5. Selected Hillsborough Bay nutrient inputs (NH_3-N and PO_4-P) expressed as a percent of N and P assimilated annually by phytoplankton. N and P assimilation by phytoplankton computed using the Redfield C:N:P ratios of 106:16:1.

	NH_3-N		PO_4-P	
	moles m^2-yr	%	moles m^2-yr	%
Phytoplankton	7.8		0.49	
Sediments	2.68	34	0.67	140
Alafia River	0.024	0.30	0.25	51
COT AWT Plant	0.005	0.06	0.12	25

The supply of phosphate in Tampa Bay, including Hillsborough Bay, far exceeds the demand by phytoplankton. According to Fanning and Bell (1985) no other estuary they know of has as high a phosphate concentration as the Tampa Bay system (average = 14uM). They attribute high phosphate concentrations to leaching of Florida's phosphate beds, fertilizer drainage from agricultural lands, and industrial and sewage inputs.

On the other hand, nitrogen supplies are probably the single most important limiting nutrient to primary production in Hillsborough Bay. In particular, evaluating inputs of ammonia is an important first step in assessing the nitrogen budget. Ammonia is the nitrogen form most readily assimilated by phytoplankton (Darley 1982, Pennock 1987), and the dominant inorganic nitrogen form released from the bottom (Nixon et al. 1976, COT 1986b). Our measurement showing that sediment recycling supports a large fraction of the nitrogen needed for phytoplankton production (34%) in Hillsborough Bay are similar to the findings of Fisher et al. (1982) for each of ten shallow marine systems (mean = $35\pm8.7\%$). Annually averaged ^{14}C productivity data for those ten systems ranged from 0.15 to $2.0gCm^{-2}d^{-1}$ compared to $1.98gCm^{-2}d^{-1}$ (Johansson et al. 1985) for Hillsborough Bay. Regardless of the system's level of phytoplankton productivity, sediment recycling appears to supply roughly one-third of the water column nitrogen demand. Hillsborough Bay's sediment recycling rates lend support to the Fisher, Carlson and Barber (1982) observation that system production and benthic nutrient recycling are functionally interconnected processes. However, it is important to realize that system productivity in estuarine systems, such as Hillsborough Bay, may primarily be driven by point and non-point nutrient sources, and not by sediment recycling. Increases in point and non-point nutrient inputs sustain greater levels of primary production and eventually create additional sediments of high organic content. The nutrients contained within these sediments are recycled and, in turn, further enhance the inorganic nutrient pool available to primary producers.

As part of the FDER wasteload allocation study, McClelland (1984) produced a nutrient box model for Tampa Bay. He calculated that all non-point and point sources, including storm water runoff, only amounted to one-third of the nitrogen released from the sediments. Adding these inputs to the benthic fluxes still only account for about 50% of the nitrogen needed to support the observed primary production. Other sources of nitrogen are supplied by *in situ* water column regeneration and possibly sediment resuspension. Also, some nitrogen could be lost from the system by bacterial denitification. These are among several processes that have not been addressed in Hillsborough Bay or the Tampa Bay system in general.

CONCLUSION

The soft, muddy, high organic sediments and their associated fauna found in Hillsborough Bay are important for nutrient regeneration and oxygen demand. These processes appear to be related to the water quality and "health" of the bay ecosystem. The location and areal coverage of the soft sediments is relatively well known (see above). Sub-bottom profiling by the BSG in 1986 revealed that the soft sediment deposits in central Hillsborough Bay may be thicker than 3m in some places. However, the recent history and accumulation rate of these sediments is largely unknown.

Doyle et al. (1985) carbon dated the bottom of sediment cores at five locations in Tampa Bay including one taken in Hillsborough Bay. We used this information and calculated an average sedimentation rate over the length of the cores of only 6.0 cm/100 yr. However, this rate may not represent sedimentation occurring in the soft areas of central Hillsborough Bay, since all cores, except one anomalous core from middle Tampa Bay, were taken in sandy sediments. We know that fine sediments accumulate rapidly in recently dredged areas with limited circulation. For example, rates of 10 cm/yr or more have occurred in Bayboro Harbor (Young 1984), a small mid-Tampa Bay embayment, and The Kitchen, located in southeastern Hillsborough Bay.

A detailed study to determine geologically recent sedimentation patterns of soft sediments in Hillsborough Bay is presently being planned between the BSG and the University of South Florida Marine Science Department. The study will attempt to identify controls and processes governing recent sedimentation in Hillsborough Bay, including anthropogenic impacts by analyzing core samples. A similar study of contaminated soft sediments found in the lower Hillsborough River has been initiated by the COT Stormwater Division in cooperation with the Florida Institute of Technology.

Information on surface sediments and their relationship to the nutrient budget and water quality conditions of Hillsborough Bay is critical to realize possible management options for this stressed marine ecosystem. Recent improvements in Hillsborough Bay water quality (HCEPC 1987 and COT 1988) appear related to recent reductions in nutrient loadings from sewage (Garrity, McCann and Murdoch 1985) and fertilizer industry effluents (Estevez and Upchurch 1985). To effectively alleviate eutrophic conditions of an estuary, efforts should be aimed at decreasing point and non-point nutrient inputs. Point and non-point nutrient inputs may ultimately be the cause of high organic sediments deposits. The removal of high organic containing sediment would only result in a short term reduction of sediment nutrient inputs. Other nutrient inputs, left unchecked, would recreate the high organic sediment deposits previously removed. Consequently, costly management undertakings, such as selective dredging of these deposits (see FWPCA 1969), may never be needed and must be avoided until potential impacts from these sediments on the Tampa Bay ecosystem are better understood.

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STORMWATER INPUTS TO TAMPA AND SARASOTA BAYS

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INTRODUCTION

This paper presents information regarding stormwater inputs to Tampa and Sarasota Bays. Discussions will center primarily on the urban rather than agricultural aspects of stormwater. Information will supplement previous data on overall watershed characteristics and stream or river flows to Tampa and Sarasota Bays. Unique rainfall characteristics for the Tampa Bay area as they relate to runoff quantity and quality will be discussed, as well as urbanization patterns and changes in land use which cause natural stream flow to be characterized as urban runoff. Runoff volumes are compared for the Tampa and Sarasota Bay systems to other Gulf coast areas. In addition, loadings for selected constituents are presented for various land use and treatment scenarios.

PHYSICAL SETTING

The watersheds tributary to Tampa and Sarasota Bays are shown in Figures 1 and 2, respectively. For the Tampa Bay system the surface water area of Tampa Bay is approximately 400 square miles, while the area of tributary watershed is approximately 1800 square miles, a ratio of 4.5 to 1, watershed to bay surface area (Treat, 1982). In the Sarasota Bay system the water surface area is approximately 40 square miles and the tributary area is approximately 30 square miles excluding the Phillippi Creek watershed, which is approximately 50 square miles, a ratio of 0.75 (or 2 to 1, depending upon whether Phillippi Creek is included).

PREVIOUS RESEARCH

A significant amount of data has been collected on urban runoff in selected tributaries to Tampa Bay. Prior to 1975, information was primarily quantity-based and resulted from studies on flooding. From 1975 to 1983, however, two major projects were conducted which resulted in significant research on rainfall, runoff quantity, and runoff quality. The first of these two studies was a cooperative program instituted by the U.S. Geological Survey (USGS) and five local governments between 1975 and 1979. In this study, nine urban gauging stations were installed in mixed land use basins ranging from approximately 0.3 to 3.0 square miles. Both runoff quantity and quality were collected through the duration of the study and published in two separate USGS reports, one quantity based (Lopez, 1983) and one quality based (Lopez, 1984).

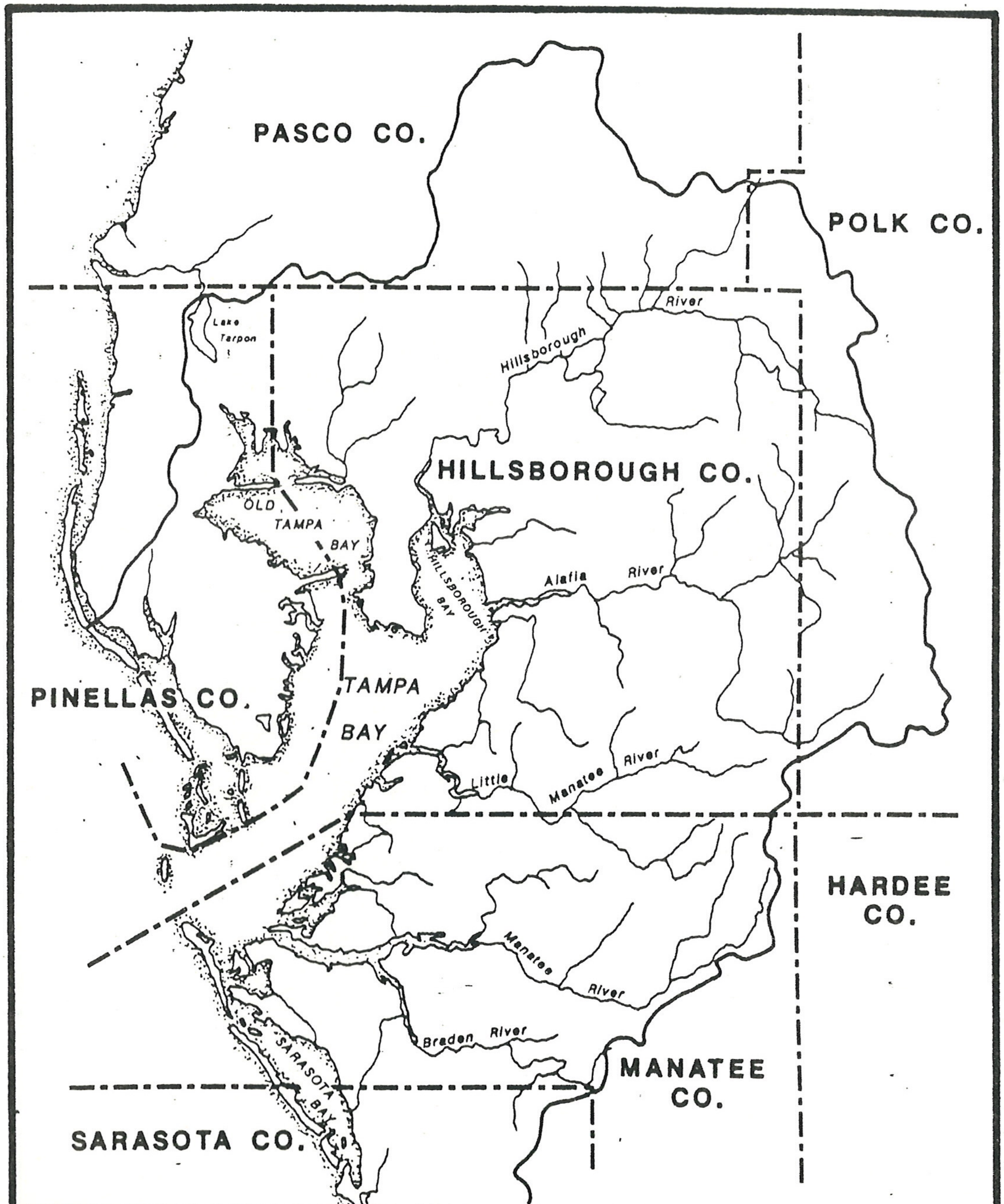

FIGURE 1 TRIBUTARY WATERSHEDS TO TAMPA AND SARASOTA BAYS

SOURCE: USGS,1984,TREAT,1982

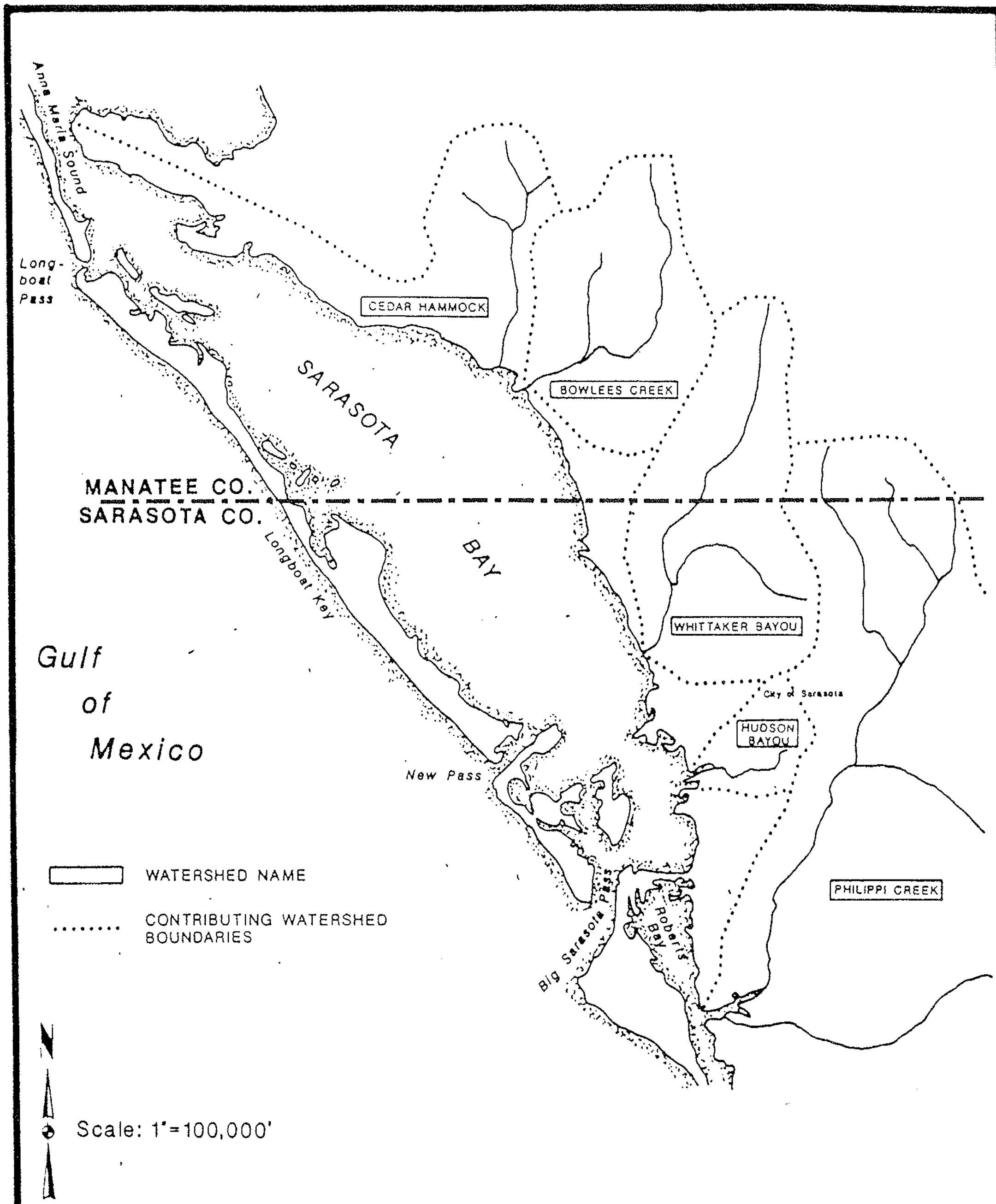

FIGURE 2 TRIBUTARY WATERSHEDS TO SARASOTA BAY

SOURCE: WANG ET AL., 1985

In 1980 the city of Tampa was selected by the U.S. Environmental Protection Agency (EPA) as one of 28 locations for the Nationwide Urban Runoff Program (NURP). This was a three-year study during which four homogeneous land use gauging stations were implemented: low and high density residential, commercial, and highway watersheds which were less than one square mile. Rainfall quantity and quality, and runoff quantity and quality were collected at the sites. By selecting homogeneous land uses this study contrasted the previous USGS study.

The location and source of the previously described urban runoff stations are shown graphically in Figure 3. Information is available from 13 stations surrounding Tampa Bay. However, little or no data is available on watersheds tributary to Sarasota Bay, which appears to be an area where data collection is needed in order to more fully characterize urban non-point source pollutant loadings.

As a result of the USGS and NURP data, regression equations were developed for selected constituents which allow the estimation of non-point source pollutants to Tampa Bay. This information may be transferrable to the tributaries of Sarasota Bay; however, it would be advantageous to have data with which to verify the validity of equations and develop site specific information on the Sarasota Bay area. These regression equations and estimates of non-point source loadings were used in Waste Load Allocations (WLA) studies for both Tampa and Sarasota Bays. Major reports which have been produced in the Tampa Bay area containing urban runoff data or information have been utilized in preparation of this paper. These reports are listed in the Literature Cited.

RAINFALL

The Tampa Bay area experiences a sub-tropical pattern of rainfall which produces unique seasonal characteristics which affect the quantity and quality of urban runoff. It is important to describe the rainfall characteristics of the Tampa Bay area in order to have an appreciation of this seasonality and variability in rainfall. Data which are presented within this section were developed as part of the NURP studies by Metcalf & Eddy, 1983, utilizing hourly rainfall data from Tampa International Airport from 1948 through 1979. During that period the variation in total annual rainfall was approximately 29 to 74 inches. This is a variation from the most dry to most wet year of approximately 45 inches. Variations of mean monthly rainfall ranged from approximately 1.4 inches in May to 8.5 inches in July, with approximately 60% of the total annual rainfall occurring from June through September. This summer rainy season produces the most significant portion of the runoff volume to the bay systems. The rainfall data reveal that approximately 90% of all storms which occur in the Tampa Bay area have 1.0 inch or less volume.

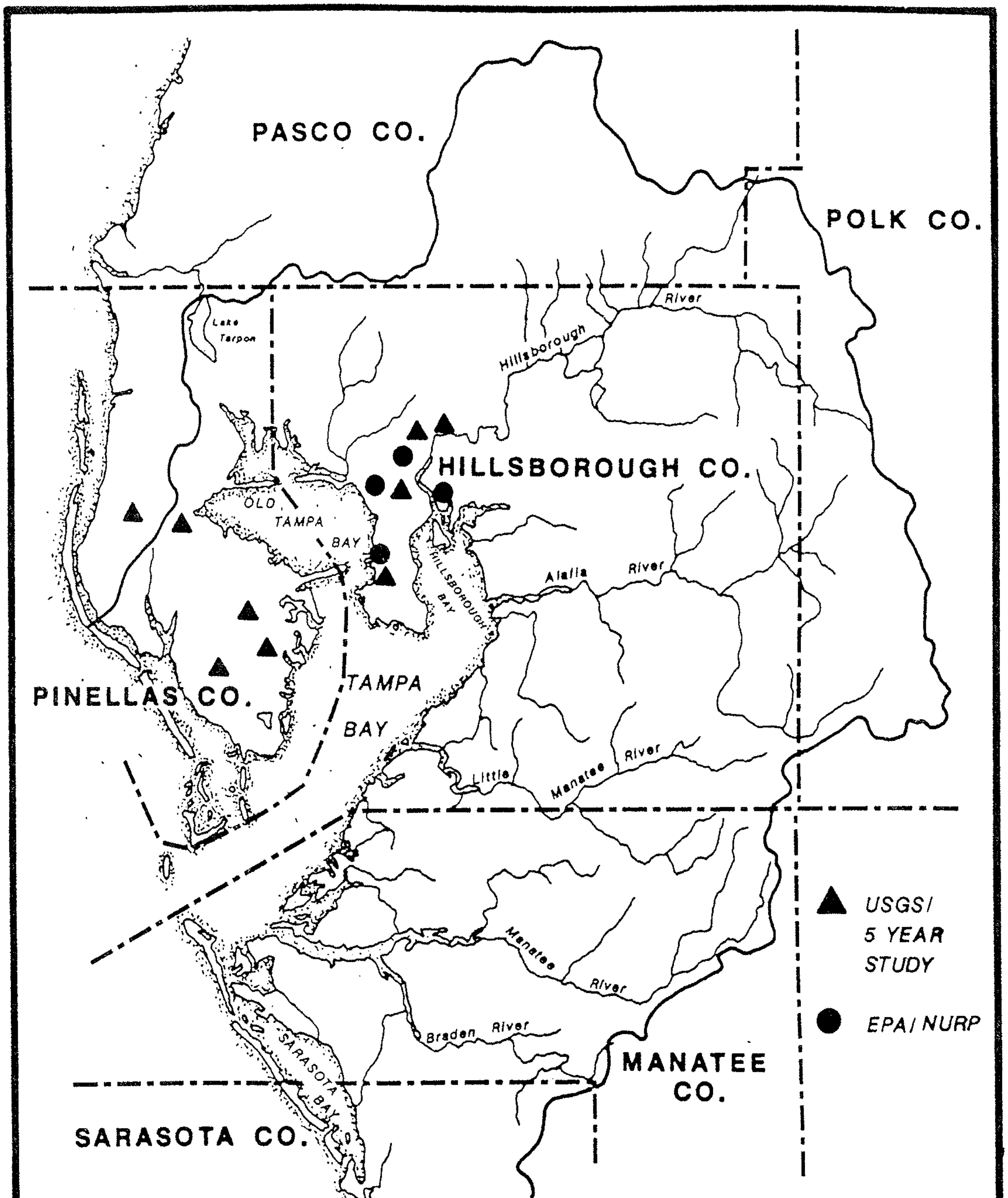

FIGURE 3 URBAN RUNOFF QUANTITY AND QUALITY SAMPLING STATIONS

A great deal of variability in rainfall occurs between summer thundershowers and winter frontal storms. During the summer months this area experiences short duration thunderstorms which produce most of the rainfall. Approximately 60% of all storm events which occur in the Tampa Bay area have a duration of four hours or less (Figure 4). Summer thundershowers also exhibit higher intensities than the longer, less intense winter frontal storms. Another important characteristic of rainfall in this area is the time between storms which relates directly to pollutant build up and to the concentration of storms washed off developed areas. Thirty percent of all storms occurred with a separation of 24 hours or less, 40% had a separation of 48 hours or less and 50% of all the storms occurred within 72 hours of each other.

When compared to runoff quantity and quality data, these weather data reveal that during the summer months (June - September) storms of short duration, high intensity, and short periods of antecedent dry conditions produce high volumes of runoff with generally lower constituent concentrations due to very little opportunity for build up of particulate matter. On the other hand, winter frontal storms are of longer duration, with less intensity and have much longer periods of time between storm events. This allows particulate matter to build up with concentrations generally higher for winter runoff events. These factors are important to the ecology of the bay with regard to mass loadings for certain parameters and the event specific toxicity of others.

LAND USE AND URBANIZATION

Urbanization in the Tampa and Sarasota Bay areas has resulted in the modification of natural watersheds to residential neighborhoods, apartment complexes, industrial, commercial, and agricultural land uses. As a result of this urbanization, the water quality and quantity entering Tampa and Sarasota Bays has been modified. Urbanization began in the St. Petersburg, Tampa, and Bradenton/Sarasota areas and spread out from those urban cores. Urbanization within Pinellas County has been most rapid, encompassing nearly the entire County. Urbanization in Hillsborough County has spread out radially to the northwest and east from the City of Tampa. Development around Bradenton/Sarasota has been primarily close to the coast between the two cities. Current land use distributions within the areas tributary to Tampa Bay are shown in Table 1. Only 16.6% of the total area of the watershed is forest or natural. Approximately 60% has been developed as pasture and crop land, and approximately 25% of the entire 1,800 square mile watershed is urbanized.

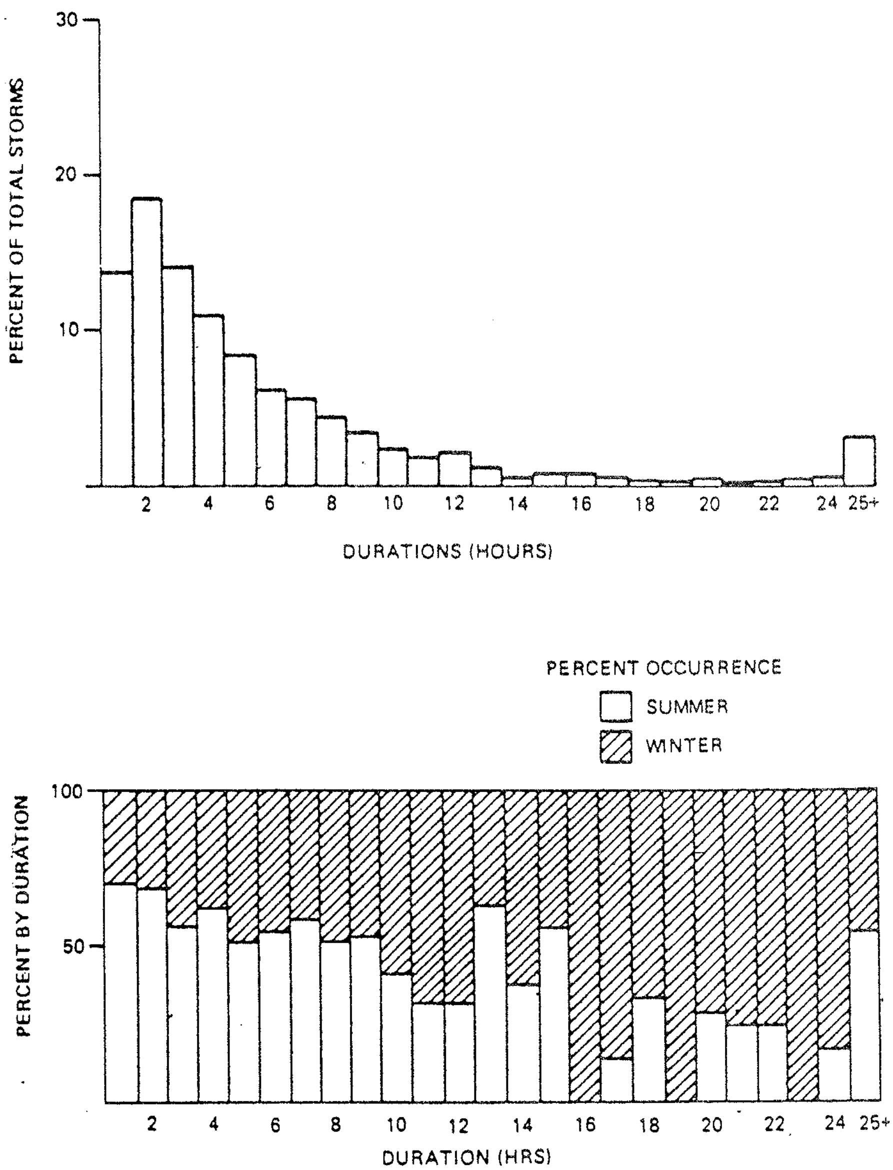

FIGURE 4 DISTRIBUTION OF STORMS BY HOURLY DURATION

SOURCE: METCALF & EDDY,1983

Table 1. Land use distribution within Tampa Bay tributary watershed (1983). (From Hartigan 1984)

Land Use	% Total Area	Subtotal
Forest	16.6	16.6
Cropland/other rural	21.3	
Pasture	38.9	60.2
Urban residential/other	16.2	
Urban commercial/industrial	7.0	23.2
	100.0	100.0

Such land use distribution can be translated into geographically specific areas that produce modifications to the quantity and quality of runoff (Figure 5). Areas of generally high, medium and low concentration of urbanization directly relate to areas which produce high, medium, and low volumes of runoff and poor, moderate and good (relatively) water quality from runoff.

URBAN STORMWATER CHARACTERISTICS

It is important to describe the characteristics of the stormwater collection systems in the Tampa and Sarasota Bay areas in order to fully understand the quantity and quality of resulting runoff. The Tampa and Sarasota Bay areas are fully served by separate storm and sanitary sewer systems. Unlike many areas in the northeast and other parts of the country which have combined systems; this area is fortunate in that most if not all sanitary sewage is collected, treated, and then discharged in dedicated systems on a continuous basis, whereas stormwater is collected in separate systems and may or may not be treated. The most heavily urbanized areas shown in Figure 5 are serviced by closed storm sewer systems which consist of inlets, pipes, collector systems and major outfalls. Some major ditches and outfall canals exist in the heavily urbanized areas. In the light urbanized areas or areas of moderate urbanization, stormwater collection is accomplished more through neighborhood ditches, rural roadway sections and canals.

The Tampa Bay area has one of the highest rates of runoff in the entire gulf area. The density of development in Pinellas County produces runoff intensities comparable only to New Orleans and Houston (Figure 6). Combining densely populated, established areas and rapidly urbanizing surrounding areas results in the highest runoff volumes of any metropolitan area (multiple counties) tributary to the Gulf of Mexico (National Ocean Service, 1985). Needless to say, such level of urbanization and runoff volume results in local flooding problems. It would be a fair assessment to say that the primary focus of local attention at the City, County, and State level is on the quantity of runoff and flooding, rather than water quality under existing conditions with current federal funding and local/state regulatory mandates (treatment for new construction only).

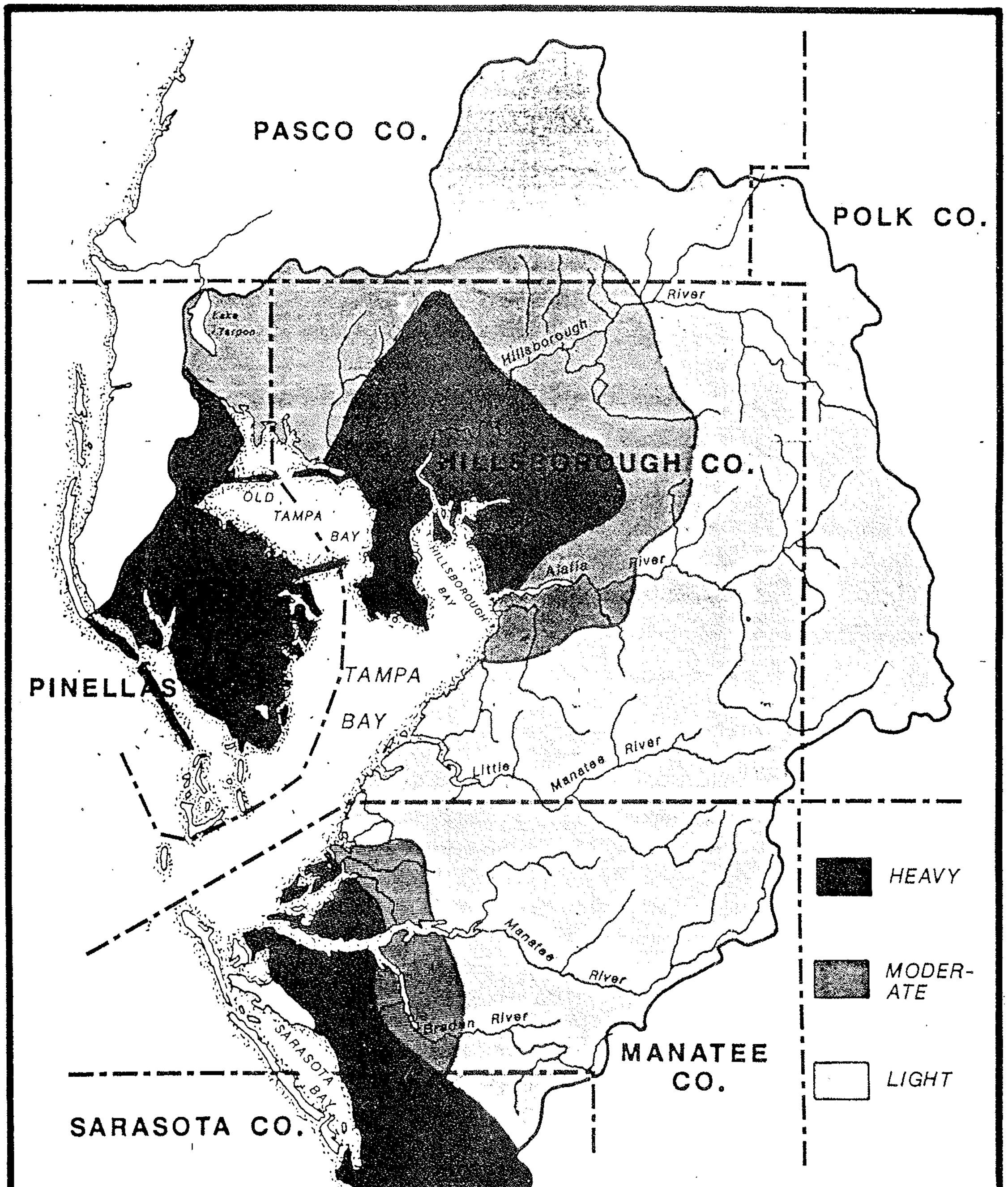

FIGURE 5 CONCENTRATION OF URBAN DEVELOPMENT CONTRIBUTING TO STORMWATER LOADINGS

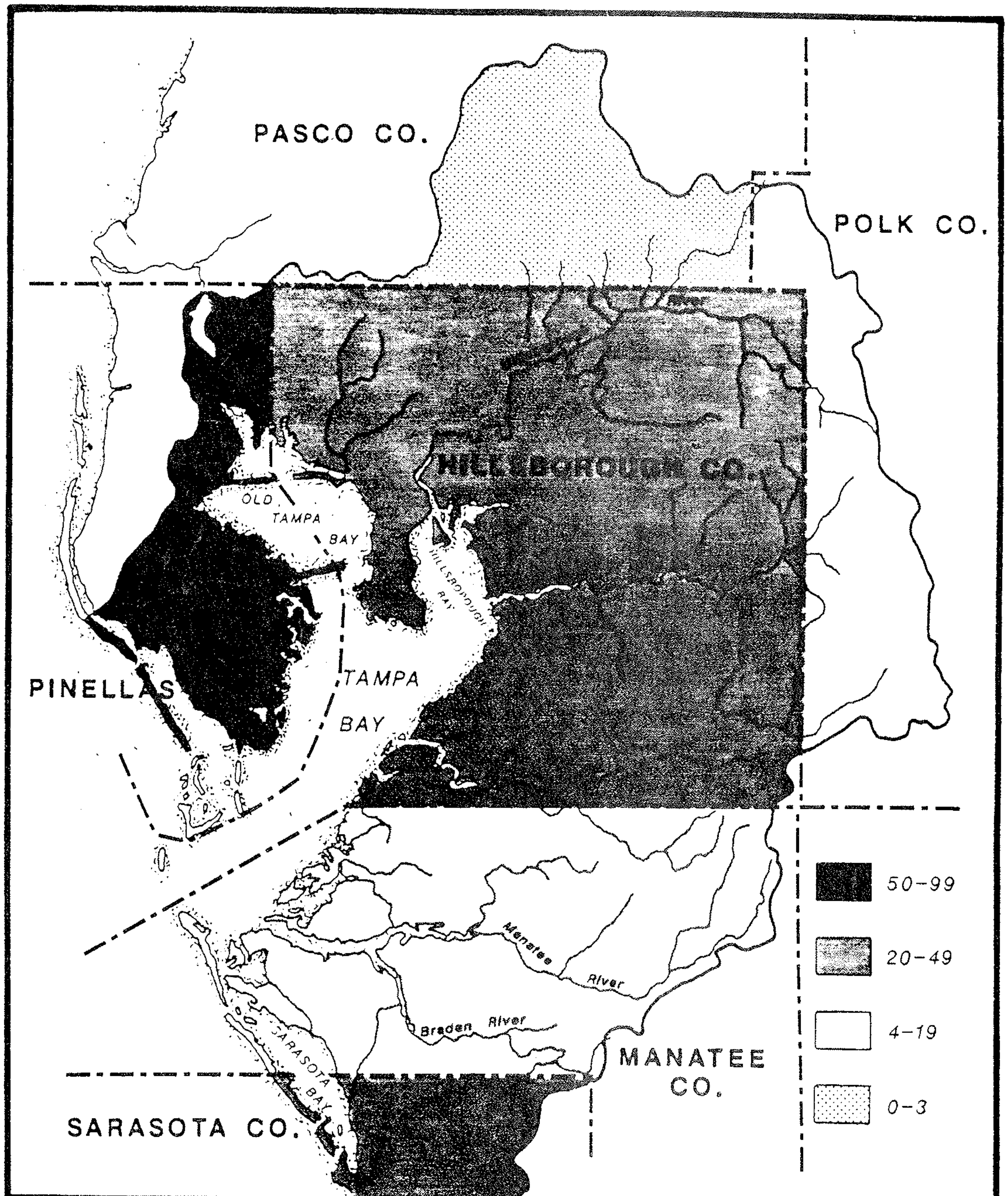

FIGURE 6 STORMWATER RUNOFF FROM URBAN AREAS
Millions of gallons of runoff per square mile per year, circa 1980.
SOURCE: NATIONAL OCEAN SERVICE, 1985

Storm sewer systems that have been put in place during the last century were built without benefit of water quality treatment or best management practices. Water quality regulations in the state of Florida and specifically in the Tampa and Sarasota Bay areas were being developed during the period from approximately 1980 to 1982, were formalized between 1982 and 1984 and began rigorous implementation from 1984 to the present. Because the vast majority (possibly up to 90% or more) of the current urban buildout in areas tributary to Tampa and Sarasota Bay occurred prior to 1982, it may be assumed that these areas are discharging untreated, non-point source pollution.

In order to better illustrate the effects of urbanization and non-point source controls on stormwater loadings, the results from two wasteload allocation studies performed either by or at the request of the Florida Department of Environmental Regulation (FDER) can be presented. Non-point source loading was one of the major pollution inputs to the wasteload allocation. Estimates of non-point source loadings in both the Tampa and Sarasota Bay studies were calculated using the USGS regression equations and/or NURP data.

The analysis for the Tampa Bay system was performed using three land use conditions: 1) the entire tributary watershed as 100% forested or natural; 2) current land use distributions; and 3) future land use distributions.

Table 2. Ratios of natural and year 2000 land use loadings to current (1983) conditions. (From: McClelland, 1984.)

	Loading Ratio*		
Land Use	Total N	Total P	BOD_5
Natural (100% forested)	0.64	0.29	0.38
Year 2000 with no NPS controls	1.10	1.05	1.13
Year 2000 with urban and agricultural BMP's	0.99	0.85	0.99

*Numerical average of values for Old Tampa Bay, Hillsborough Bay and Main Bay.

Using the existing condition as a base, estimates for the contribution of "Natural Conditions" ranged from 29% to 64% of the current loading for phosphorus, BOD, and nitrogen. In other words, only 29% to 64% of the current loading of these constituents reached the Tampa Bay system under natural conditions. Between 110% to 113% times the loading occurs for future conditions with no controls and from 85% to 99% occurs for future conditions with controls.

The results of the wasteload allocation performed for Sarasota Bay indicates that this system is much more sensitive to urban runoff loadings. Loading values for the wasteload allocation study in Sarasota Bay are shown in Table 3. Non-point sources contribute by far most of the total suspended solids and 30 to 50% of the nitrogen and phosphorus loadings to the bay, respectively.

Table 3. Comparison of total loads to Sarasota Bay 1981-1982 (lbs. per day). (From Priede/Sedgwick, Inc. 1983.)

	TSS	TN	TP
Point sources (measured)	166	1,079	253
Non-point sources (estimated)	3,021	291	118

These data indicate that the levels of non-point source loadings to Tampa and Sarasota Bays are significant with existing levels of urbanization. Realizing that urbanization will continue as the population in Florida continues to increase, non-point source loadings will have to be dealt with. New sources as well as existing development will have to be examined in order to manage and improve runoff quality. The retrofitting process for stormwater quality treatment in existing developed areas will be costly, controversial and time consuming.

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HEAVY INDUSTRY OF TAMPA AND SARASOTA BAYS

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INTRODUCTION

Tampa and Sarasota Bays and their tributary rivers and creeks have long been used as receiving bodies for man's domestic and industrial wastes. Tampa's first centralized sewage system was built in the 1890s and discharged directly into the Hillsborough River and Hillsborough Bay (Garrity, McCann, and Murdoch 1985). As early as 1929, the Alafia River was used as a dump for both rock and waste waters by the phosphate industry (Lewis and Estevez 1988). Galtsoff (1954) stated more than 30 years ago that Tampa Bay was "grossly polluted" because of municipal sewage discharges and industrial wastes from 6 phosphate mines, several citrus canneries and miscellaneous plants. He also noted that most of Sarasota Bay was closed to shellfishing because of pollution. A listing of waste discharges into the two bay systems in 1968 included 18 industrial sources in Tampa Bay and 15 industrial sources in Sarasota Bay (McNulty, Lindall, and Sykes 1972). Discharges into Sarasota Bay were primarily from small laundries with average daily discharges of 0.01 million gallons/day (mgd). Tampa Bay industrial sources included citrus processors, chemical companies, electronics manufacturers, and a variety of other industries; the average daily discharge for most of these industries was reported as unknown. A review of point source discharges in the Tampa Bay area in 1980 listed 59 sources (Moon 1985). This list includes both domestic and industrial discharges but did not include specific information regarding the types or quantities of materials discharged.

Current records of the Florida Department of Environmental Regulation (FDER) show a total of 75 permits for the discharge of industrial wastes into the surface waters of Tampa and Sarasota Bays. Three power plants located on Tampa Bay which withdraw bay water for condenser cooling and discharge thermal effluent into the Bay are not included in these FDER permits. Eighteen of the 75 permits are for sources considered as major discharges; the remainder are for minor discharges. Sewage and sewage treatment plant effluents are not included in this total.

SARASOTA BAY

The area surrounding Sarasota Bay has never been heavily industrialized. Fourteen of the 15 sources of industrial discharges into the bay listed by McNulty et al. (1972) were laundries or car washes. The remaining source, a manufacturer of television and communication equipment, was listed as the largest source of discharge into the bay via Phillippi Creek with average daily discharges of 0.02 mgd. None of these sources hold a current FDER discharge permit and presumably have either been connected to municipal sewage systems or have ceased discharging wastes.

The City of Sarasota reverse osmosis (RO) water treatment plant is the only source of industrial discharge into Sarasota Bay currently under permit by DER. This source is considered by FDER to be a major discharge. Several smaller RO plants discharge wastewaters into coastal bays just to the south of Sarasota Bay proper. The effect on the overall water quality of Sarasota Bay caused by industrial discharges is probably insignificant when compared with the effects of nonpoint source runoff (Giovannelli, this report) and sewage plant discharges.

TAMPA BAY

Historically the phosphate and related chemical processing industries have been the main source of industrial wastewater discharges into the Tampa Bay system. Seven of the 18 sources of discharge in the late 1960's were of this type (McNulty et al. 1972). In 1987, of the 18 active permits issued by the FDER for major sources of industrial discharge, nine were for wastes discharged by facilities which manufactured sulfuric and phosphoric acids, triple superphosphate and other phosphate related compounds. The remaining major sources of discharge consisted of two citrus processors, the City of Tampa water treatment plant, and 6 power plant discharges. Three of these power plants withdraw a combined total of 1942 mgd of bay water for condenser cooling. The location of major industrial waste discharges into the surface waters of Tampa Bay and its tributaries are shown in Figure 1. Discharges from phosphate processors and power plants are important because of the number and the quantity of their effluents. Specific problems associated with these industries will be discussed in greater detail.

Along with the 18 major discharges, an additional 57 minor sources have active FDER discharge permits or are under enforcement for unpermitted discharge. These sources represent a diversity of industrial activities including several phosphate and fertilizer producing facilities, citrus canneries, laundries, and petroleum refining and storage operations. Only two minor sources of industrial surface water discharge are presently permitted by FDER in Sarasota County. Both permit holders are shell pit operations which occasionally discharge

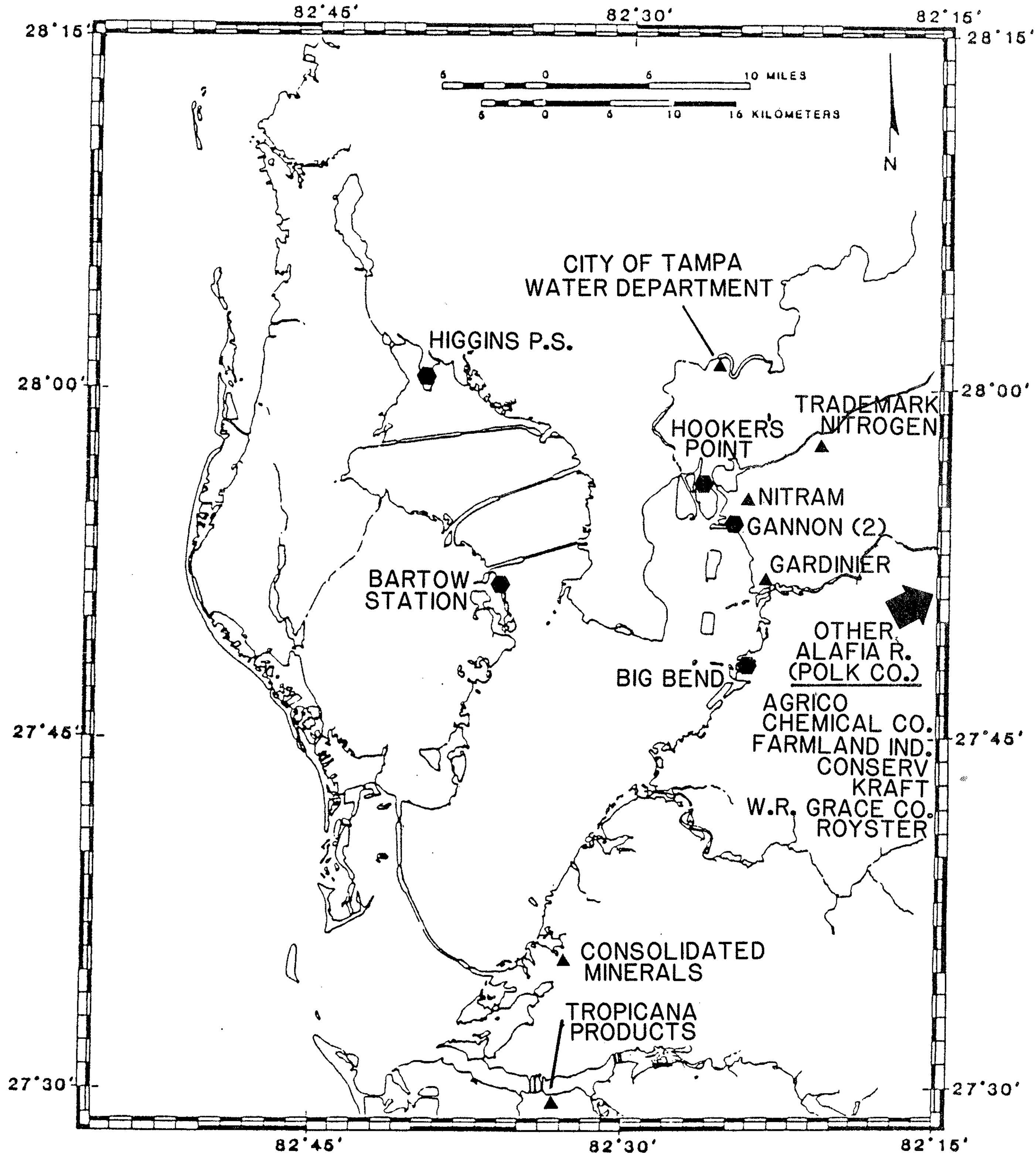

Figure 1. Sources of industrial discharge into Tampa Bay.

water generated from the dewatering or washing of sand and fill mined at the sites.In general, the makeup and quantities of many industrial discharges into Tampa Bay have not been well documented (Tampa Bay Regional Planning Council 1985).

Most of the industrial development in the Tampa Bay area has occurred on the northern and eastern sides of Hillsborough Bay primarily due to the presence of phosphate deposits east of the bay and the subsequent development of the Port of Tampa (Tiffany, this report). Hillsborough Bay has therefore received the greatest quantities of industrial wastes through its tributary rivers and creeks. One of the most heavily industrialized tributaries is Delaney Creek, a small creek which drains approximately 11,069 acres on the northeastern shore of Hillsborough Bay (TBRPC 1986b). Delaney Creek has been the receiving body for the wastes from a fertilizer manufacturing plant, plants which manufacture lead acid batteries, a trucking company, and at least 15 wastewater treatment plants. Although the creek is designated as Class III waters as defined by the Florida Administrative Code, Chapter 17-3 (recreation and propagation and management of fish and wildlife), it does not meet these standards. A recent study of the minor tributaries of Tampa Bay has resulted in several recommendations for the restoration and management of Delaney Creek (TBRPC 1986b).

Phosphate Industry

Phosphate deposits were discovered in the 1880's in the Bone Valley region of Polk County east of Tampa Bay. This discovery not only led to direct impacts on the bay's waters, but also greatly influenced the development of the Port of Tampa (Fehring 1985; Tiffany, this report). Small scale mining operations began in 1888 when the Arcadia Phosphate Company shipped ten carloads of ore mined from the Peace River at Arcadia to a fertilizer works in Atlanta (Blakey 1973). The mining industry gradually grew during the early part of the 20th Century. During this period most of the high grade ore was shipped overseas; the lower grade ore was used domestically as fertilizer. Tremendous expansion of mining activities occurred following World War II in response to the growing worldwide demand for phosphate fertilizers. During the late 1940's and early 1950's, the industry began to construct chemical plants making phosphoric acid, superphosphate, triple superphosphate and other concentrated phosphate products for fertilizer. The industry continued to expand in the 1960's with production reaching its zenith in 1967. This industry has suffered declines in recent years due in part to increased phosphate production worldwide and uncertain economic conditions.

Several activities are associated with the phosphate industry in southwest Florida, including mining and beneficiation of the ore, transportation of the ore and fertilizer products, and processing the raw ore into concentrated compounds for fertilizer. Each of these activities has caused environmental problems. Strip mining, for example, causes habitat loss and can contaminate both surface and groundwaters. Spillage during transport enriches waterways and causes noxious algal blooms.

Beneficiation is the initial processing and concentration of the phosphate ores near the mine site. After the overburden is removed,the ore is scooped from the ground and transported as a slurry to a nearby processing plant. The ore is crushed, washed, separated from the clay and sand, sized through a series of screens, and dried. This process creates a slime of water and finely ground clay and sand which has no economic use and must be stored and dewatered. Dewatering requires a period of several years due to the small size of the clay particles, and the slimes are stored in large, diked impoundments. Retaining dikes have broken a number of times over the years, releasing large quantities of slime into both the Peace and Alafia River. These breaks have resulted in vegetation being covered by thick layers of slime for miles downstream and have caused massive fish kills.

Chemical plants which process the raw phosphate ore into enriched phosphate compounds used in fertilizer present a different set of potential problems. Phosphate rock, as mined, is chemically bound to fluoride, which makes it practically insoluble in water. The fluoride must be removed before the ore can be processed further. Fluoride removal is accomplished by the addition of heat or acid, which releases free fluoride. Gaseous fluoride is highly toxic to plants, animals, and humans. In the past, fluoride was released to the atmosphere, but following a public outcry in the 1950's after agricultural crops and cattle began dying, the industry undertook measures to recover the fluorides. Fluoride is produced in almost every stage of chemical manufacture (Blakely 1973), and one chemical plant located on Tampa Bay near the mouth of the Alafia River discharged fluorides directly into Tampa Bay for many years. In seawater, fluoride reacts with calcium carbonate to form fluorite. Fluorite forms a hard crust on the bay bottom and destroys benthic infauna. These deposits can extend hundreds of meters from the discharge. At this plant, areas of continous fluorite crust and fluorite chips cover nearly 100 acres of bay bottom.

Gypsum is another byproduct of the enrichment process. Like the slimes generated at the mine site, gypsum must be dewatered and is stored at the chemical plants in large impoundments called gypsum stacks. Gypsum stack wastewaters are treated by liming and settling before they are released into Tampa Bay. Frequent spills have occurred from the gypsum stacks at the two chemical plants located on Tampa Bay causing adverse environmental effects.

Many environmental problems associated with the phosphate industry have been eliminated by measures to control discharges, but potential problems of spills from mine slime ponds and chemical plant gypsum stacks remain. The slowdown of the phosphate industry has raised the possibility of the closure of mines and chemical plants. Bay management plans must include provisions to ensure that, following closure, slime ponds and gypsum stacks are sealed and properly maintained to prevent future catastrophic spills of toxic substances into the environment.

Power Plants

There are currently five steam electric generating plants located along Tampa Bay which withdraw bay water for once-through condenser cooling (Table 1). Approximately half of the generating units are more than 30 years old, and the oldest --Units 1 and 2, Tampa Electric Company's (TECO) Hookers Point Plant-- are approaching 40 years of age. Only in the last 20 years with the construction of ever larger generating units and their concomitant increases in cooling water withdrawals have power plants been recognized as major sources of industrial discharge. The 15 units constructed prior to 1965 utilize a combined total of 1,721 mgd for cooling, whereas the 6 units built since 1965 withdraw a combined total of 1,987 mgd, nearly three times the amount per unit.

The primary environmental impacts caused by plants which use once-through cooling are of three types; one concerns the discharge of heated effluent, and the other two are associated with the withdrawal of cooling water (Figure 2). Thermal discharges can have adverse effects on the biota in the vicinity of the power plant. Impingement is the removal and death of organisms trapped on plant intake screens. Entrainment causes death of planktonic organisms carried through the plant cooling system. Additional adverse impacts can be caused by the addition of chlorine at plant intakes to reduce in-plant fouling, runoff from coal storage piles, and discharges from slag and ash settling ponds. The slag handling system at the Big Bend Station, for example, uses an average of 7 mgd in conjunction with a settling pond. This water is ultimately discharged into Tampa Bay (TBRPC 1983).

Table 1. Five power plants located in Tampa Bay (from TBRPC, 1985).

Characteristics	Hookers Point	Gannon	Big Bend	Higgins	Bartow	
1) Numbers of units		5	6	4	3	3
2) Number of pumps		10	12	8	6	6
3) Start-up dates:						
Unit 1		1948	1957	1970	19511958	
Unit 2		1948	1958	1973	19531961	
Unit 3		1950	1960	1976	19561963	
Unit 4		1953	1963	1985	-- --	
Unit 5		1955	1965	--	-- --	
Unit 6		--	1967	--	-- --	
4) Nameplate MW	233	1,270	1,823	138	494	
5) Total flow (MGD)		257	1,267	1,388	234	561

MW = megawatts; MGD = million gallons per day.

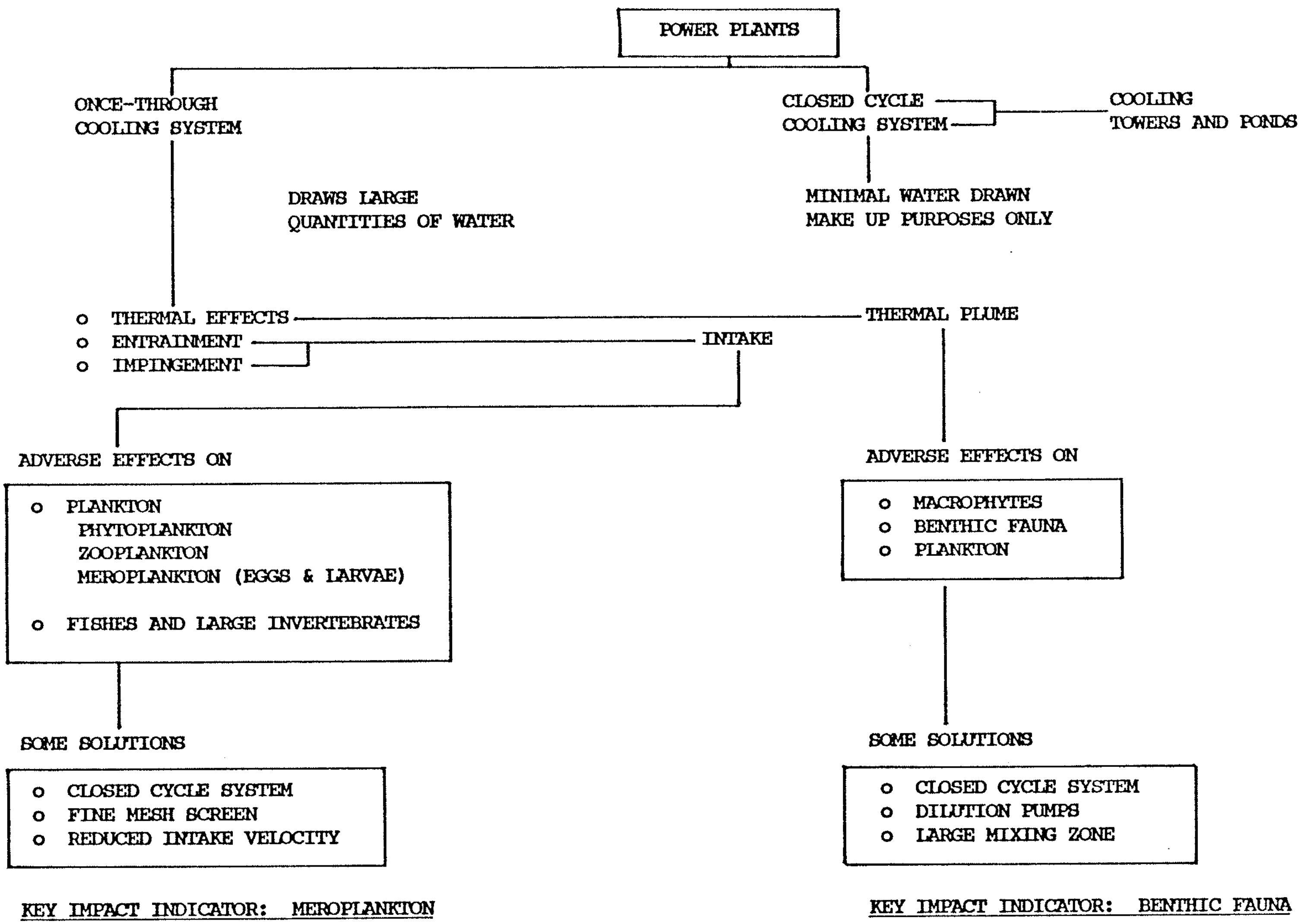

Figure 2. Primary environmental effects (and some possible solutions) caused by power plants with once-through cooling.

In southern estuaries like Tampa Bay, thermal impacts associated with the heated water discharge initially caused the most concern among regulatory agencies. Thermal effects are the most visible of power plant impacts; steam rises from the water surface on cool days; rafts of foam float on the discharge water; and once abundant grassbeds are greatly reduced in size or disappear altogether. Several studies have been conducted to determine the ultimate impact of thermal discharges at power plants on Tampa Bay and in other nearby estuaries. Studies of the benthic fauna at TECO's Big Bend Station on eastern Hillsborough Bay (Mahadevan, Culter and Yarbrough 1980) have indeed found that thermal effects are severe in the vicinity of the plant discharge. These effects are manifested by low overall faunal densities, an abundance of opportunistic and pollution indicator species and dissimilarities with unaffected open bay stations. These effects, however, were limited to the main discharge canal (Figure 3). Mild adverse effects represented by a higher incidence and abundance of opportunistic species and lower species diversity were limited to a 1 km area outside the plant discharge canal. Impacts caused by plant cooling water discharges were difficult to discern from the wide seasonal and year-to-year fluctuations in the benthic community (Figure 4). Overall, the studies concluded that adverse thermal effects were minimal.

Impingement of fishes and macroinvertebrates on the travelling intake screens was also studied at Big Bend (TECO 1980b). These studies found that an average of 132 fishes and 125 macroinvertebrates were impinged per unit per day. Dominant species trapped on the screens were sand seatrout, bay anchovies, horseshoe crabs, and pink shrimp. Based on these studies it was concluded that impingement at Big Bend was negligible in comparison to the total population and the sport and commercial catch. These impingement rates were deemed to be acceptable at Big Bend.

Studies designed to quantify the levels of entrainment of fish eggs and larvae through condenser cooling systems have been conducted at three of the five power plants on Tampa Bay. These studies found that entrainment levels were high at all three plants (Table 2). At Big Bend, for example, an estimated 86 billion (8.6×10^{10}) fish eggs and 26 billion (2.6×10^{10}) fish larvae were entrained per year by the plant (Phillips, Lyons, Daily and Sigurdson 1977). The majority of these were eggs and larvae of forage species such as bay anchovies, silver perch, gobies and blennies. Annual entrainment by all five power plants located on Tampa Bay has been estimated to be 2.74×10^{11} fish eggs and 8.30×10^{10} fish larvae which ultimately results in the annual removal of 2.84×10^{10} (nearly 3 billion) harvestable adults from the Tampa Bay commercial and recreational fishery (TBRPC 1985). Regulatory agencies ruled that entrainment levels at Big Bend were unacceptable and that offstream cooling or some alternate technology needed to be evaluated.

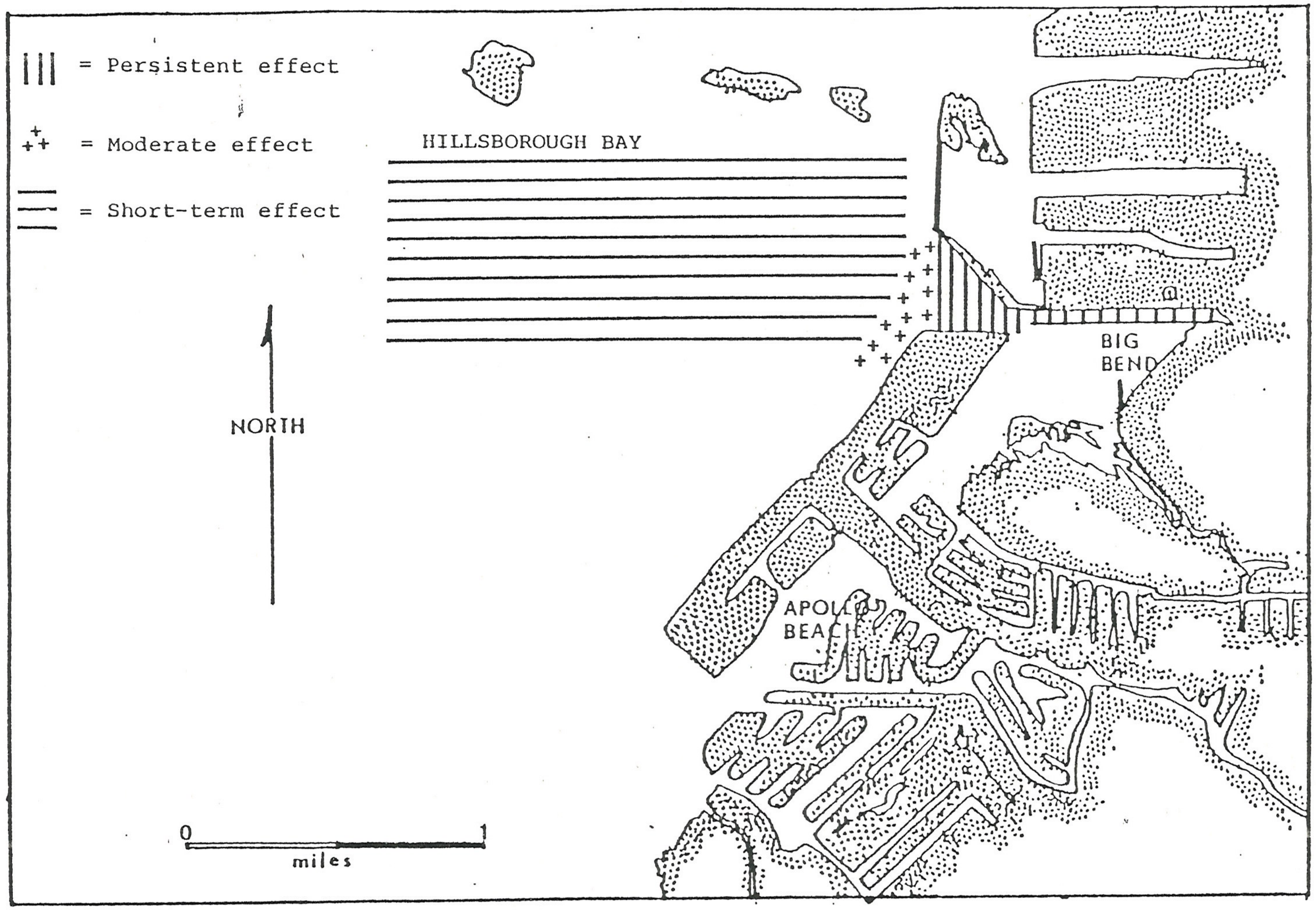

Figure 3. Thermal effect zones at the Big Bend Power Plant (from TECO 1980).

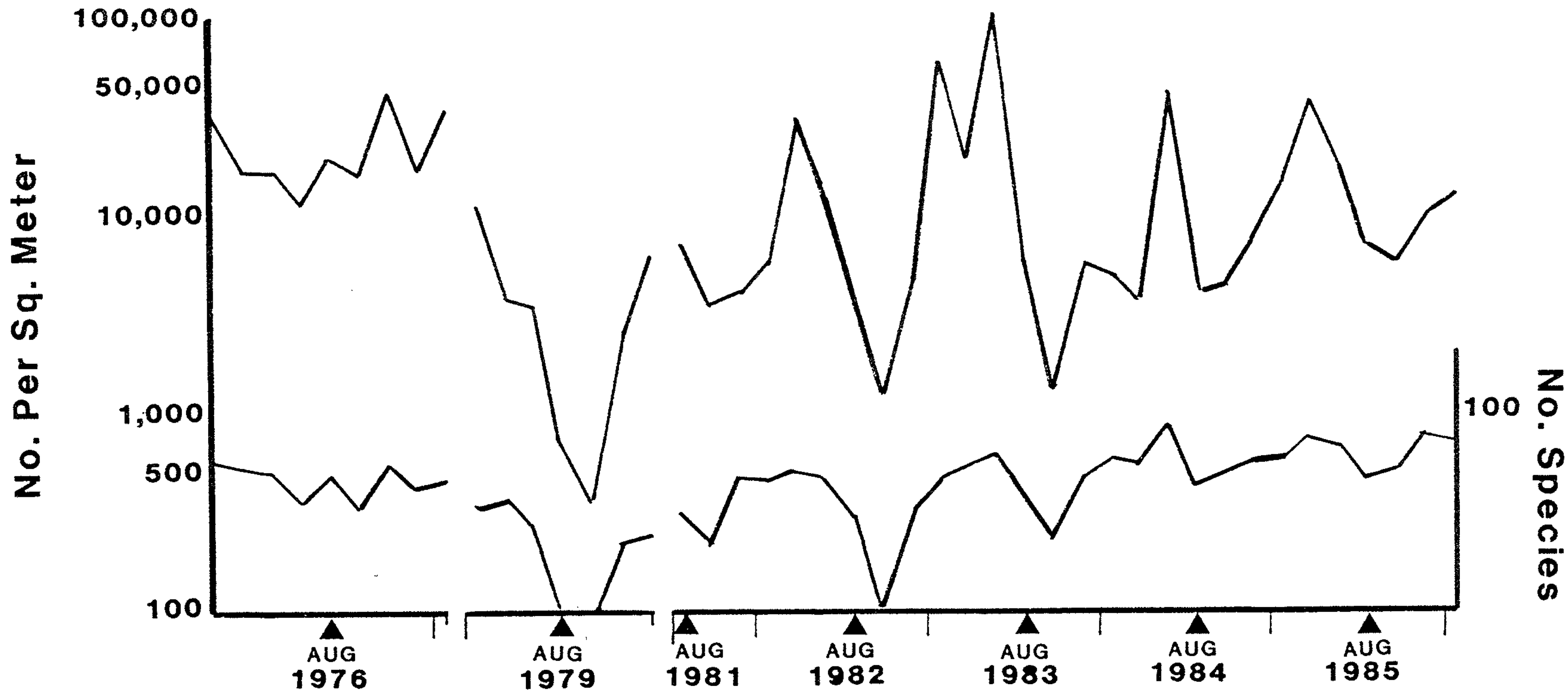

Figure 4. Temporal trends in benthic faunal density (number per square meter) and number of species at Big Bend, Tampa Bay, from February 1976 through February 1986 (from Leverone and Mahadevan 1986).

Table 2. Comparison of estimated entrainment from three power plants in Tampa Bay.

	Higgins[1]	Big Bend[2]	Bartow[3]
PLANT DATA:			
Units	3	3	3
Circulating Pumps	6	6	6
Volume (MGD)	234	1,388	561
ENTRAINMENT ESTIMATES:			
Total Eggs	5.9×10^{9}/9 mo	8.6×10^{10}/yr	5.2×10^{10}/9 mo
Total Larvae	3.8×10^{9}/9 mo	2.6×10^{10}/yr	5.3×10^{9}/9 mo

[1]Weiss et al. 1979
[2]Phillips et al. 1977
[3]Florida Power Corporation 1986.

Several methods to reduce entrainment were considered (TBRPC 1986b). One alternative to offstream cooling was to backfit the intakes of two units with continuously-washed, fine-mesh screens and an organism return system. If successful, this system could be an appealing option. At minimal cost, it would reduce the combined entrainment of four units to below that of three units fitted with conventional screens. Studies to evaluate the feasibility and effectiveness of installing a fine mesh screen system were conducted in 1980 on a prototype intake structure constructed in the plant intake canal. Survival of fish larvae impinged on the prototype fine mesh screen was disappointing, ranging from 0 to 22% for the most abundant species. On the other hand, approximately 80% of bay anchovy eggs and 95% of drum eggs, the two most abundant egg types, hatched after the entrainment and wash procedure. Survival of the larvae of commercially abundant decapod larvae, pink shrimp (85%) and stone crab (92%), was also high. These survival rates were determined to be acceptable and fine mesh screen intake structures were subsequently built for the two units. Other power plants around the bay have not been adapted to reduce entrainment, however.

SUMMARY

Industrial development came late to the Tampa Bay area. Phosphate mining and processing, once the economic mainstay of many bay area communities, began less than 100 years ago. It was not until after World War II that explosive population growth and enormous expansion of the phosphate industry occurred simultaneously. This combination demanded the construction of more and larger power plants to supply electricity to light and cool homes and businesses, as well as to meet the needs of the increasingly mechanized phosphate industry. The citrus processing industry also continued to grow during this period, and its products are now marketed worldwide.

Resources in the early days, including both land and water resources, were considered to be limitless. Blakey (1973) in his overview of the prevailing mentality stated:

> Men slashed the earth in the pursuit of raw materials, and consideration of immediate profit dictated the relationship with the land. Capitalism and free enterprise rolled up their sleeves in a "lowest cost conspiracy" with the consuming public. Industry developed the resources and produced the goods at the lowest possible cost, and the public joyously bought the goods to enjoy a better life.

Waste materials were disposed of at the lowest cost wherever it was convenient -- a nearby river, or directly into Tampa Bay.

As the population of the Tampa Bay area continued to grow, the need for open spaces, clean water for fishing and swimming, and the desire to eliminate noxious odors emanating from the bay became apparent. Environmental controls were gradually instituted, and untreated wastes could no longer be dumped indiscriminately.

Environmental impacts resulting from man's past carelessness should serve as a reminder for future generations that vigilance must be maintained. Future needs include better maintenance of gypsum stacks at chemical processing plants, as evidenced by the spill of nearly 13 million gallons of acid slime which inundated tidal marshes in March 1987 following heavy rains. As recently as May 1988, 40,000 gallons of phosphoric acid were accidentally released into the Alafia River causing a major fish kill. In the case of power plants, entrainment losses to fish populations have been judged to be acceptable once units are equipped with fine mesh screens. The cumulative loss at plants not yet equipped with screens needs to be addressed. Without a better understanding of how these fish populations function, it is virtually impossible to assess the ultimate consequences of continued or increased entrainment of the early life stages. Much progress has been made toward controlling industrial impacts upon Tampa Bay, but much more work remains to be done.

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PORTS AND PORT IMPACTS

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INTRODUCTION

The purpose of this paper is to familiarize the reader with one of the major influences on this region, collectively the ports and their attendant impacts.

Of the 14 deepwater seaports in Florida, 3 are located on Tampa Bay (Figure 1). There are no commercial ports on Sarasota Bay. Although this discussion will center on these ports, specifically the Port of Tampa (Florida's largest port), Port Manatee (4th largest), and the smaller Port of St. Petersburg, keep in mind that there are many other maritime commercial and recreational activities and centers in both Tampa and Sarasota Bays which exert a significant impact on the local environment. Some of these include the many marinas and private docks which dot the waterfront, commercial fishing docks, and several large private terminal facilities such as those operated by power companies which bring in oil and coal for generating electricity. Certainly these operations all have similar potential for impacting the environment, as do the major ports (Phillips et al. this report). All have a potential for spills, use channels and landside facilities which were created at some expense to the environment, and, in some ways, have a greater impact than the actual port facilities. For example, Estevez and Merriam (this report) discuss the typical shoreline of Sarasota Bay and its extensive alteration for water related activities. At the recent Sarasota Bay Area Scientific Information Symposium (SARABASIS), it became readily apparent that recreational boat traffic and navigation congestion problems constitute significant concerns to Sarasota area residents.

HISTORICAL OVERVIEW

The ports of Tampa Bay have evolved from a long history of maritime commerce that dates back to the Post Columbian era, when Cuban fishermen utilized the vast resources of Tampa and upper Sarasota Bays to supply their growing population with a source of protein-rich food. It was not until after Florida's statehood in the 1850's, just prior to the Civil War --when Tampa farmers started shipping cattle to Cuba-- that the Cuban fishing industry faded. By this time, Fort Brooke (a military post in the upper Bay system) was well established and provided protection from hostile Indians. A brisk maritime trade developed, serving the growing civilian communities around Tampa Bay, and it provided the only connection to other markets.

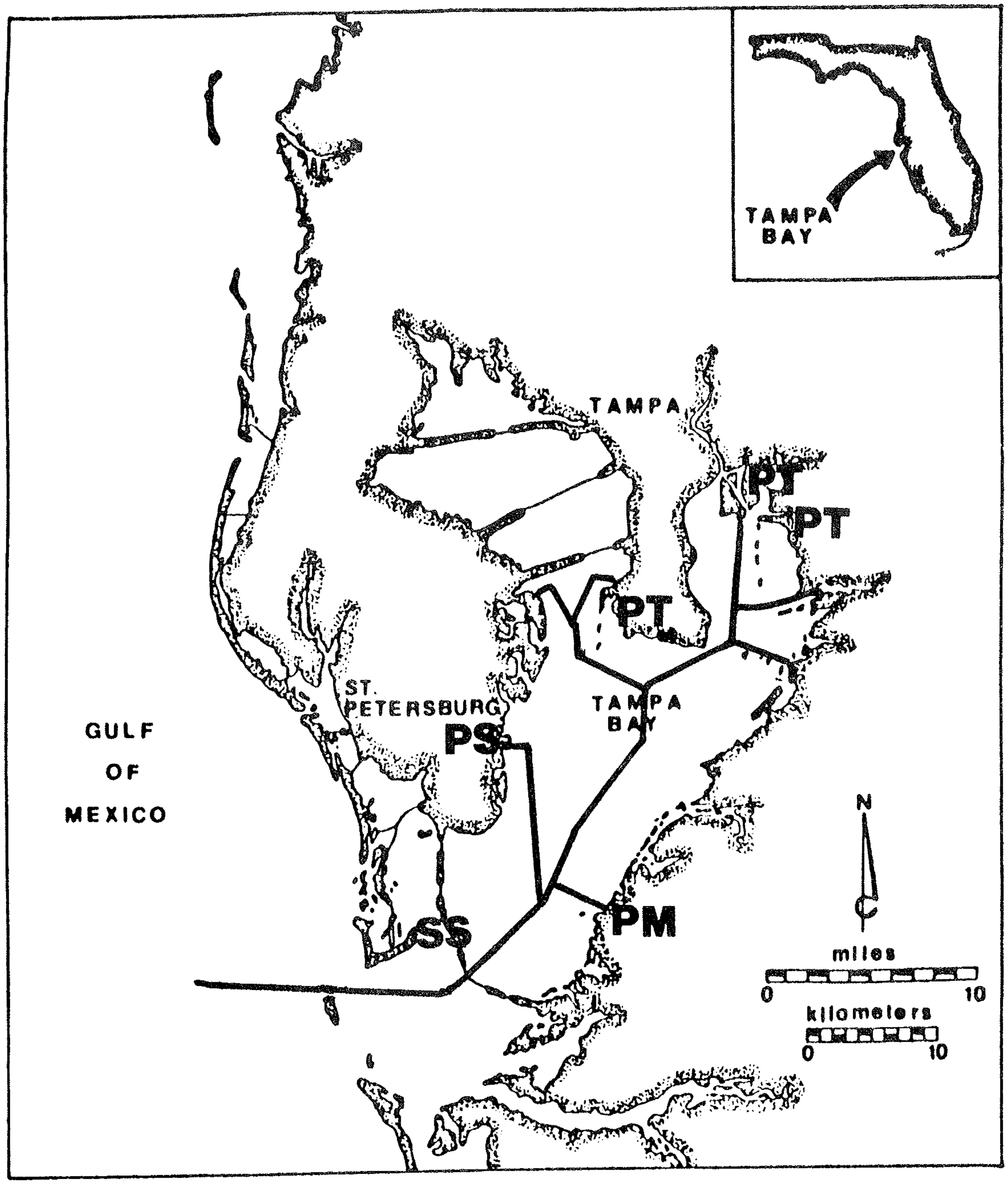

Figure 1. The Tampa Bay estuary, Florida (adapted from Lewis 1976; TBRPC 1985). PM, Port Manatee; PS, Port of St. Petersburg; PT, Port of Tampa; SS, Sunshine Skyway Bridge.

In the late 1800's an event occurred which would forever change the Bay area. Phosphate was discovered in ancient Pliocene deposits along rivers and underground throughout the region. Mining operations rapidly expanded to strip the region of its valuable mineral deposits, and in fact the growth and competition which accompanied this new industry rivalled the 1840's gold rush in size and in notoriety. Regardless, this singular discovery would eventually change the entire economy of the region, and with it the actual physical nature of Southwest Florida as we know it today. This would be accomplished not just through mining operations themselves, but through the physical changes imposed on shoreline shipping communities such as Tampa and its relatively pristine Bay ecosystem. By 1908 when the first large vessels entered Tampa Bay to haul phosphate rock out, the die was cast for physical alterations to the entire Bay system. To illustrate the impact, it is necessary to discuss phosphate very briefly.

Twenty percent of the world's phosphate production and 80% of all United States phosphate output takes place just east of Tampa and Sarasota Bays (Florida Phosphate Council, personal communication). Approximately 50% of all tonnage leaving Tampa Bay is composed of phosphate related products. Even though this is down from 80% just 10 years ago (primarily due to expanding foreign sources and a depressed fertilizer market), it still makes the Port of Tampa alone one of the top 10 ports tonnage-wise in the United States. By comparison, the ports of New Orleans and Houston may be far greater in physical size; but considered as a whole, the ports of Tampa Bay together are now the 4th largest in the country in terms of both tonnage and vessels called to port (Florida Ports Council, personal communication). Last year alone, these ports handled over 50 million tons of waterborne commerce -- more than any other port in the southeastern United States.

As one looks at the 70-some miles of 43 foot deep channel traversing the Bay (Figure 1), keep in mind that its initial development was almost exclusively related to phosphate trade and the need for deeper channels to allow deep-draft ocean-going vessels to navigate. Although petroleum (and its related products) is a major maritime cargo and is the principal incoming product to Tampa Bay, it is historically a distant second-runner in use of the channels compared to phosphate products. Other major cargoes include cement, coal, animal feeds, scrap metal, and lumber. Several cruise lines are also located in Tampa Bay ports.

Before discussing the channels and port development impacts, mention of a quirk regarding the channel and its strategic importance for Tampa Bay is in order. Tampa Bay, and specifically Port Manatee, is the closest United States deepwater port to the Panama Canal. <u>ALL</u> large ships sailing in and out of Tampa Bay must use the main ship channel, and in turn, must pass under the Sunshine Skyway Bridge. Besides the significance this bridge has regarding circulation problems in the Bay, ironically this so-called Gateway to Tampa Bay can also be a closed gate. An act of war or a navigational error resulting in collision with the bridge (as occurred several years ago) can bring the bridge down into the channel, blocking all navigation in or out. In fact, contingency plans exist to drop the main span purposely into the channel to prevent foreign intrusion, if necessary. The non-obstructed nature of the mouth of Tampa Bay has previously been considered a positive military advantage since the late 1890's when Teddy Roosevelt and the Rough Riders sailed out from the Tampa docks on their voyage to Santiago.

Dredged Material

Due to the inherent shallow nature of Tampa Bay, dredging and filling activities are critical to all port operations, including continual development of port facilities onshore and on bay fill sites, the creation of additional channels for navigation, and the routine maintenance of existing channels and berth spaces. These activities have resulted in the dredging of more than 100 million cubic yards of material for the creation of the large port infrastructure alone. The United States Geological Survey estimates that no less than 13 square miles of Tampa Bay has been lost to dredge and fill activity (TBRPC 1985) (Figure 2). This does not include dredged spoil volumes generated during recent channel maintenance. As a result of the last federal dredging project which just ended, that figure amounted to over 70 million cubic yards. Presently the Corps predicts that the removal of another several million cubic yards will be required by Fiscal Year 1989. (For an historical chronology of dredging and filling projects which have resulted in the present system of channels and fill sites, the reader is referred to Fehring 1985; Goodwin 1984; Lewis 1976; TBRPC 1985; USCOE 1983).

Fehring (TBRPC 1985) classified dredged material disposal strategies in Tampa Bay into five general areas: ocean dumping, estuarine open-water disposal, estuarine habitat-creation disposal, estuarine confined disposal, and upland confined disposal. The reader is referred to that publication for a thorough discussion of the benefits and problems associated with each type of disposal. For the sake of brevity here, estuarine disposal will be presented as a single topic.

Estuarine disposal of dredged material is now strictly regulated by numerous governmental agencies through an elaborate permitting system (predominantly administered by the United States Army Corps of Engineers and the State of Florida Department of Environmental Regulation). Unconfined estuarine disposal is no longer considered a viable method, due to water quality problems and the destruction of benthic habitat (see Lewis 1976; and previous papers in this report which address water quality, circulation, and biology).

All three of Tampa Bay's ports have evolved on dredged and filled coastal habitats. For example, although Port Manatee's beginnings were conceived on highly altered coastal lands already used for agriculture, the spoil generated from dredging the basin and berthing slips was fortuitously placed waterward to create more land for port development (Figures 3 and 4). Related channel dredging resulted in a spoil island created from large rock and sand materials, while fines and sand were placed landward (discussed later). Even more dramatic is the filling

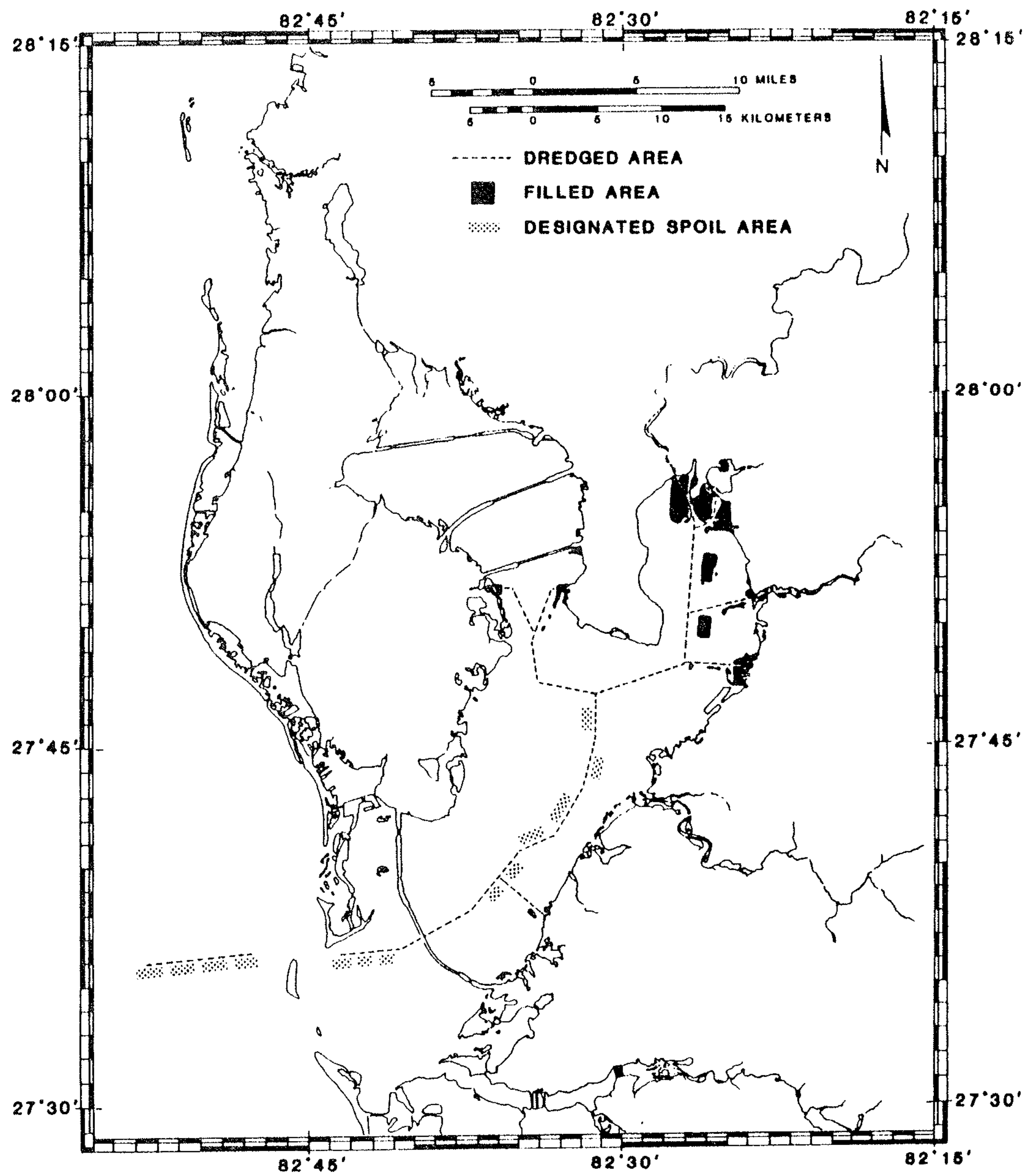

Figure 2. Areas of Tampa Bay dredged or filled for port development, past 100 years (adapted from Fehring 1985).

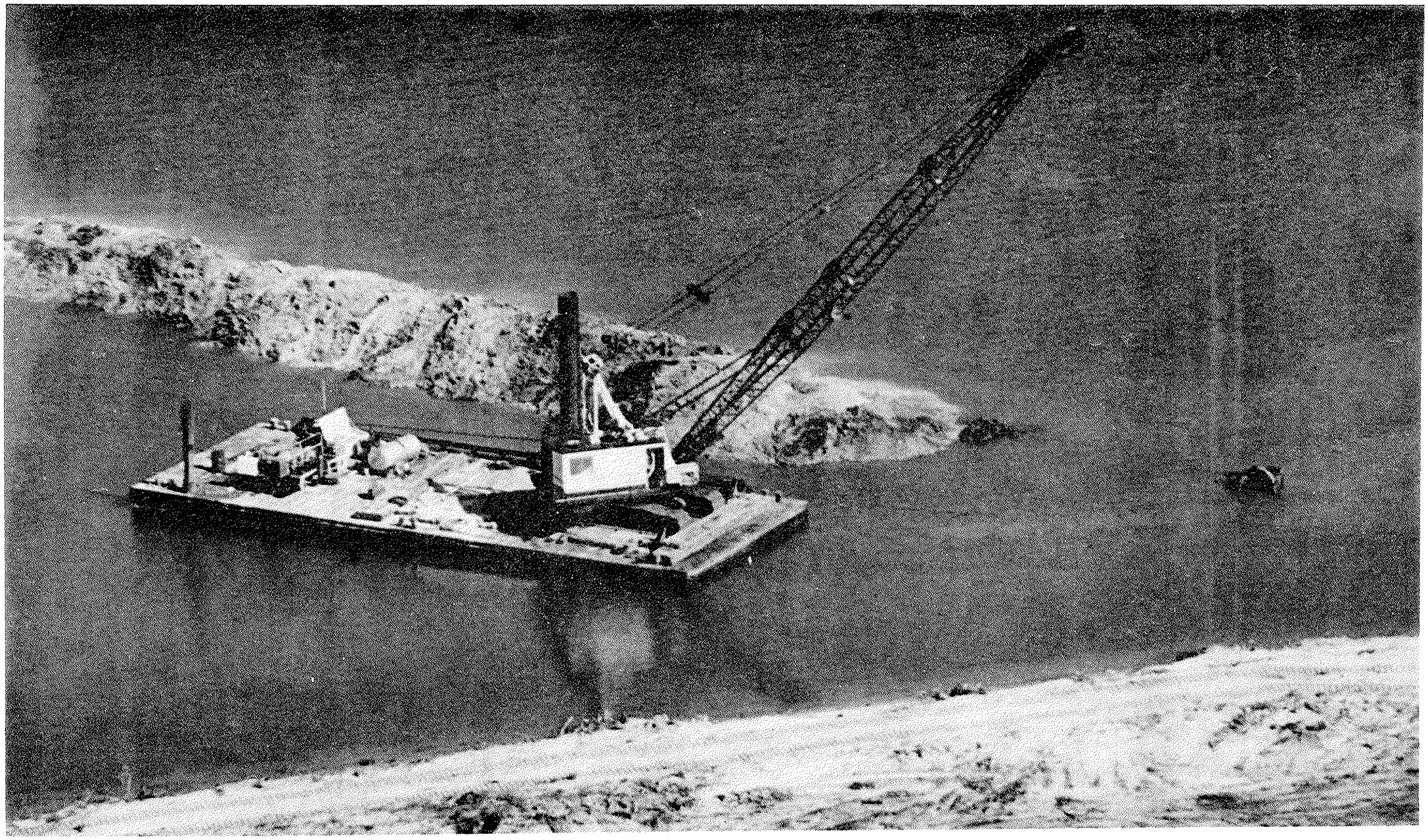

Figure 3. Port Manatee Construction, 1969. Dragline building phase dike adjacent to cleared shoreline. Dredged material will be pumped behind dike to extend land seaward.

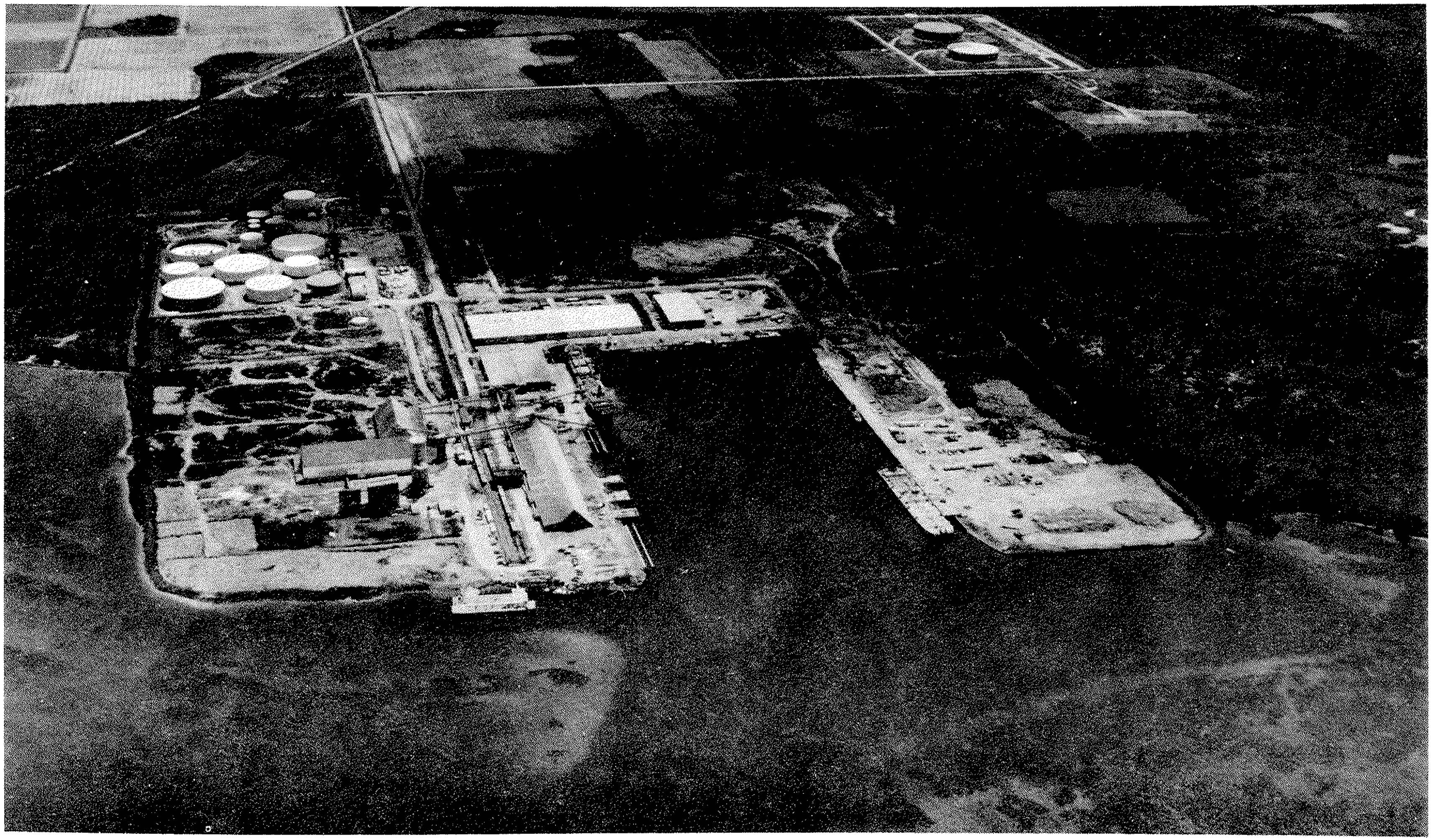

Figure 4. Port Manatee, 1981.

that has taken place in the upper Bay system during the creation of the Port of Tampa and its channels (Figure 2). The filling which resulted in the formation of Davis Island alone covered over 800 acres of Bay bottom, including productive intertidal marshlands, and that is only a fraction of the fill placed in Tampa Bay estuarine waters. Recently the Port of Tampa --in conjunction with the United States Fish and Wildlife Service--completed a mitigation study for Tampa Bay (Dial and Deis 1986) with the intention of ameliorating some of the problems of past dredging and filling activities conducted by all Tampa Bay ports and by other coastal developers. Likewise, the Tampa Bay Regional Planning Council has prepared a report (TBRPC 1985) which includes recommendations for corrective action in the Tampa Bay area.

Besides shoreline fill in the bay, numerous spoil islands have also been created (Figure 5). Most of these islands follow the ship channels for the obvious reason of disposal ease. Some of the older islands were not properly banked or diked and are eroding badly (e.g. the Hillsborough Bay spoil islands). Besides causing water quality problems, erosion is also contributing to the re-silting of the channels. Other islands, including older submerged spoil piles, are likewise eroding badly (particularly those paralleling Port Manatee's cut -- especially during northwesterly storm fronts).

However, if constructed and managed properly, spoil islands can have beneficial uses other than to provide future development sites. For example, many spoil islands in Tampa Bay are well documented breeding sites for numerous species of birds. Sarasota Bay, likewise, has many spoil islands along its Intracoastal Waterway which serve as rookeries for many birds including brown pelicans. The completion of the West Coast Inland Waterway in 1967 (Intracoastal Waterway) which runs north from Ft. Myers through Sarasota and Tampa Bays resulted in the removal of over 14 million cubic yards of material (West Coast Inland Navigation District, personal communication). The 100 foot wide channel, which is more than 150 miles in length, is replete with numerous spoil islands. It was suggested at the recent Sarasota Bay Symposium (Estevez 1988) that proper management and restoration on these islands could be a viable way to recover historic habitat lost through coastal development. This reiterates management objectives established by New College students during their study of spoil islands in Sarasota Bay several years ago (Carlson 1971).

Upland disposal of port spoil material in the Bay area is quite limited at this time. One of the largest and most notable sites used to contain spoil material generated during maintenance dredging is located at Port Manatee. Being a relatively land-rich port, Manatee has committed to contain all maintenance dredged spoil upland. Considering the spoil material as a resource, Port Manatee has designated over fifty acres of the disposal site for development of a finfish hatchery by the State of Florida Department of Natural Resources in conjunction with the Mote Marine Laboratory (Haddad, this report).

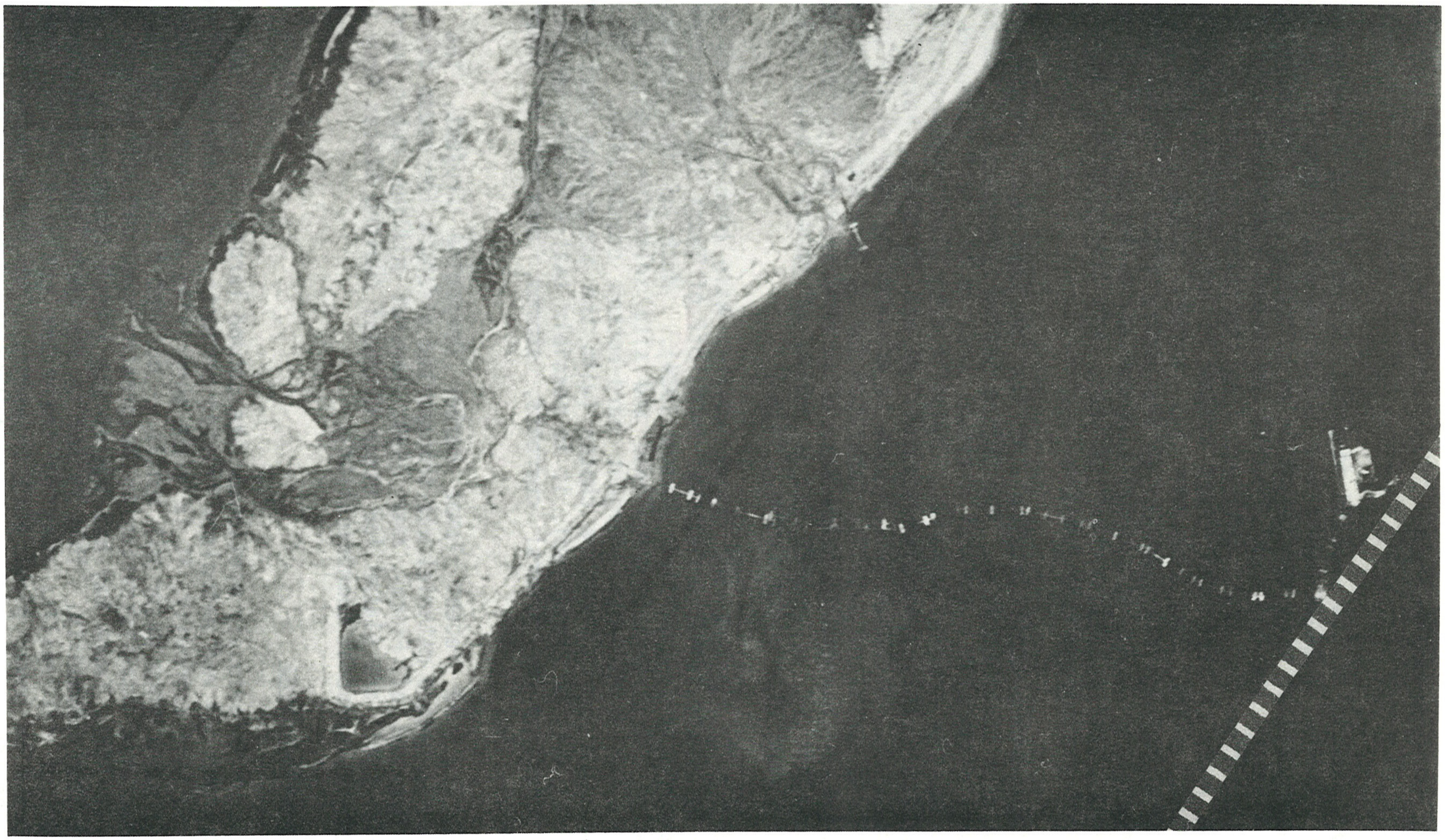

Figure 5. Spoil island construction, Tampa Bay. Hydraulic dredge pumping fill material onto incipient spoil island during creation of channel. Note boundary lines established for spoil disposal site. Wide interrupted line indicates centerline of channel.

An example of poor upland disposal is the Hendry site just south of Port Manatee. Dredged spoil was indiscriminately pumped into prime tidal creek habitat with the intention of creating an upland development site. Although the State of Florida extracted fines and much of the filled land from the owner (who was also the party responsible for the filling), much of the tidal creek system is lost forever. During the past three years Port Manatee has worked closely with several governmental and private agencies on the Hendry site, involving numerous environmental projects specifically aimed at restoring circulation to tidal areas, replanting coastal marshes, and transplanting seagrasses offshore to provide nursery habitat.

Considering spoil disposal, by far the most controversial method has been open ocean dumping. The United States Environmental Protection Agency has designated a general disposal area in the Gulf of Mexico west of Tampa Bay for dredged material. Specific dump sites used recently are located within this area approximately 13 and 18 miles, respectively, from the coast. Although this method is accepted by many as the primary method for disposal of material generated during maintenance dredging of the navigation channels in Tampa Bay, it is certainly not without impact (see Pequegnat et al., 1981 for a review of general impact analysis procedures regarding ocean disposal sites).

Numerous surveys and impact studies have been conducted in an attempt to locate suitable disposal areas off of Tampa Bay, but problems with specific sites persist (Amson 1984). Much of the controversy surrounding the disposal operations and site selection deals with the potential for disturbing emergent hard-bottom communities. Even if suitable sandy substrates are chosen (with the acceptance that benthic communities will be smothered), it is possible that off-site impacts can occur, depending on natural currents, storms, dumping at incorrect coordinates, etc.

During the recent Tampa Harbor Deepening Project, the vast majority of dredged material was transported offshore for ocean disposal. Before the end of Fiscal Year 1989, several million cubic yards of additional spoil are slated for ocean disposal (United States Army Corps of Engineers, personal communication).

Spill Considerations

As was previously mentioned, the second largest tonnage cargoes in Tampa Bay are oil and petroleum related products. Considering the heavy traffic in this commodity, it is quite surprising that Tampa Bay does not regularly experience major oil spills -- defined by the National Oceanic and Atmospheric Administration to be greater than 100,000 gallons (NOAA 1985). In fact, Tampa Bay has one of the lowest incidents of spills of any Gulf port community. This is not to say that Tampa Bay has not had its share of oil spills; many of these are not port related but are attributable to power plant fuel shipments. On the average there are between 100-150 spills per year reported to the 7th Coast Guard District (United States Coast Guard, personal communication). These spills are typically less than 100 gallons and average 30-40 gallons. This is certainly nothing compared to the Amazon Venture and her 800,000 gallon spill off Georgia in 1986, or compared to the problems the Port of Jacksonville has had with numerous recent large spills in excess of 10,000 gallons.

Tampa Bay does, however, experience many small spills into open waters which are commonly known as "mystery spills" (usually occurring at night, away from lay berths, and not traceable). These incidents usually involve the intentional pumping of bilge slops and are the most difficult to deal with because they almost always end up onshore with disastrous results. In these cases, cleanups are difficult and costly (not to mention the cost to the environment).

Dockside accidental spills are much more common than accidental open water spills and occur most of the time through human error, predominantly involving a failure to connect and disconnect hoses properly (Figure 6). When a spill does occur, cleanup can be effected fairly easily by booming off the site and using absorbent pads and snorkel trucks to pick up the residual. All Florida ports are now empowered under Florida State law (Chapter 16B-16.04, Florida Administrative Code) to have functional Discharge Cleanup Organizations, which are licensed by the Florida Department of Natural Resources, and which should be capable of containing and cleaning up all spills that occur in port. Most ports belong to cleanup cooperatives formed by the port authority and the port tenants, who in turn, hire professional third-party contractors, licensed and bonded by the State and Coast Guard to perform cleanup and disposal activities.

The National Oceanic and Atmospheric Administration indicates that more than 5,000 vessel trips per year occur in and out of the ports on Tampa Bay (NOAA 1985). Shipping routes from Tampa Bay extend throughout the Gulf of Mexico and thence worldwide. As one might anticipate, there are attendant petroleum discharges all along these routes. These discharges are defined as "operational" discharges to be polite, but they are really intentional (usually involving bilge pumping and tank cleaning). These routine, intentional discharges contribute 30 times more oil than all the accidental spills combined for the entire Gulf of Mexico (NOAA 1985). Worldwide this practice amounts to 571 million gallons annually. Until recently this was an accepted practice, but with the adoption of the new International MARPOL regulations (see Federal Register Vol. 50, No. 174:36768-36795), which now require shorebased reception facilities to be available for the pumping of bilge slops, it is expected that these figures may be significantly reduced.

Future Directions

Probably the single most significant event to take place in recent years which will have a positive effect on port operations in Tampa Bay (and in other Florida ports, as well) is the newly passed Local Government Comprehensive Planning and Land Development Regulation Act (Chapter 163, Florida Statutes; Chapter 9J-5, Florida Administrative

Figure 6. Dockside transfer of petroleum products.

Code). This Act lays the ground rules for comprehensive long range planning for future growth in Florida. The sections of the Act which most directly affect ports are the Coastal Management Element and the Port Element. As this Act applies specifically to ports on Tampa Bay, it requires completion of Comprehensive Master Plans by the end of 1988. These port Master Plans will in turn be incorporated as elements of each local government's Comprehensive Growth Plan, and more importantly, the port plans must be consistent with state mandated standards and criteria as spelled out in the Coastal Management Element and the Port Element. The ultimate goal is "to promote the orderly development and use of ports" (Chapt. 163, F.S.).

Some of the specific items for which each port will be responsible are as follows:

1. Drainage and the impact of non-point and point source pollution on estuarine water quality must be covered. This basically will entail the development of master drainage and stormwater management plans.
2. Existing natural shorelines are to be protected.
3. Natural systems Inventories will be required, with the intention of developing land use guidelines which protect or enhance existing resources.
4. An analysis of environmental, socioeconomic, and fiscal impacts of development and redevelopment will be required.
5. Contingency plans will be required for any natural disasters such as hurricanes, and for man induced hazards such as spills and fires.

All of these items and numerous others will then be subjected to extensive local, regional and State review before adoption by local ordinance.

The development of the Coastal Management Element was a major priority of the Governor's office and the Florida Department of Community Affairs. This fact is reflected in the requirements for this element, which are considerably more detailed and far reaching than those for any other elements of the Act.

In closing, most Florida ports and certainly all three deepwater ports on Tampa Bay already have begun to shift emphasis away from some of the problematic cargoes that have been pollution problems. Admittedly, the reasons are more economic than philanthropic; nevertheless, the concept of increased diversity in cargo means healthier financial systems and usually fewer environmental problems. As the ports are increasingly being adversely affected by slumps in much of the bulk cargo industry (especially phosphate products), many new items related to the food industry are being added. In particular, orange juice, frozen beef, and bananas now traverse Tampa Bay waters on a regular basis. The ports are also handling many new products related to the construction industry such as raw lumber, finished wood items, pipe, and cable. One of the newer developments to be exploited is in the area of containerized cargo.

As West-Central Florida continues to grow, the ports of Tampa Bay will continue to develop their cargo mixes accordingly. Concurrently the ports will expand as a result of increased maritime commercial activities. With adequate comprehensive master plans in place, many of the historical adverse impacts of port growth and development can be avoided.

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RESOURCE STATUS AND MANAGEMENT ISSUES OF SARASOTA BAY, FLORIDA

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INTRODUCTION

Sarasota Bay is a small, subtropical embayment on the west coast of peninsular Florida. It is connected to the Gulf of Mexico and to the southern end of Tampa Bay via Anna Maria Sound. Like much of coastal Florida, the Sarasota Bay area is experiencing rapid population growth, although most of its development having adverse environmental impact has occurred only in the last 50 years. Barrier islands between the bay and gulf are completely developed as residential, light commercial, and tourist areas. Nearly the entire upland watershed of Sarasota Bay is also developed, mostly as suburban residential and commercial areas. There are no heavy industries in the watershed, and the amount of agricultural land is low and decreasing due to urbanization. The local economy is driven primarily by retirees, tourism, and the services industry which have developed because of the bay, warm climate, and historical circumstances. The bay supports an extensive recreational industry and is showing signs of overuse. For all practical purposes, there has been little more than a century of modern settlement in the bay area, with 3 periods of major development (the Florida land boom of the 1920's; the post World War II boom; and the present "sunbelt" period of population growth.)

The bay and its watershed are situated equally in Manatee and Sarasota Counties (Figure 1). The combined population of these counties was 420,500 people in 1986 (Collins 1988). The largest cities --and county seats-- are located near the bay at Bradenton and Sarasota, in Manatee and Sarasota Counties, respectively. Bradenton Beach and the Town of Longboat Key are two small municipalities on the barrier island of Anna Maria and Longboat Key, respectively. Two other islands separate the bay and gulf south of Longboat Key (Lido, Siesta); Lido Key and a small portion of the northern-most tip of Siesta Key are within the city limits of Sarasota, and the balance or Siesta Key is part of unincorporated Sarasota County. Manatee County participates in the Tampa Bay Regional Planning Council, whereas Sarasota County is a member of the Southwest Florida Council, meaning that Sarasota Bay is divided across the middle into two separate planning bodies. Both counties and the whole bay are within the Manasota Basin of the Southwest Florida Water Management District and the Southwest District of the Florida Department of Environmental Regulation (Sauers and Patten 1981).

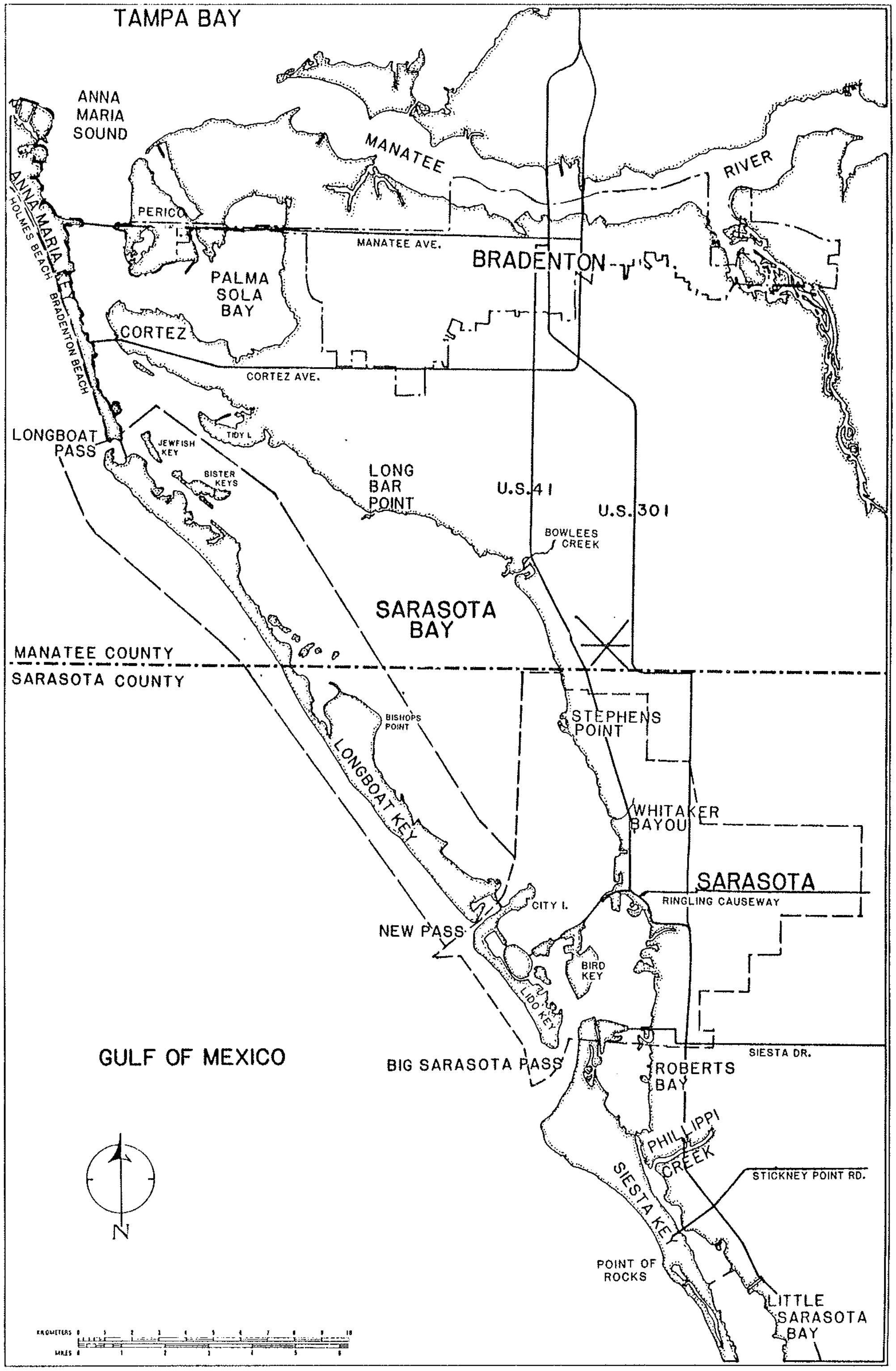

Figure 1. Sarasota Bay and surrounding inshore waters.

Resource Description

Sarasota Bay has been called a lagoon, a neutral estuary, and a bay. It is located between Tampa Bay and Charlotte Harbor, the nation's 17th and 18th largest estuaries, respectively (Seaman 1988). It exemplifies a number of water bodies along the Florida and gulf coasts by its proximity to open, shallow waters; much greater width than depth; physical dominance by wind and tides rather than tributaries; and recreational uses (Estevez 1988).

The bay area has a mean annual temperature and rainfall of 72.0^{o}F and 54.6 inches of rain per year. Most of the rain (60%) falls between June and September (Walton 1988). The bay is approximately 20 miles long and has a mean depth of 5 ft. Deeper portions of the bay's central basin are 8-10 ft deep, and Longboat Pass (between Longboat Key and Anna Maria Island) has a maximum depth of 27 ft. Extensive shallow areas bordering the bay are mudflats, seagrass beds, or wetlands. The bay is subject to a relatively low energy climate (Evans 1988). Winds vary to and from the gulf, except during winter frontal systems when northwest winds prevail. Tides are mixed diurnal and semidiurnal, with a mean and extreme range of 1.3 and 2.1 ft, respectively (Goodwin 1988, Walton 1988). Average wave heights (on barrier beaches) are about 1 ft, and sediment transport is minimal (Evans 1988, Harvey 1982).

Currents in the bay are tide and wind dominated, ranging between 0.3ft/sec in open bay areas to 1.5 ft/sec within inlets. A nodal area-- or zone of little net water movement-- crosses the mid bay area in Manatee County (Walton 1988). Flushing time for the bay in general is estimated to be 2-15 days, although actual rates depend upon freshwater inflow (DeGrove and Mandrup-Poulsen 1984; Dendrou, Moore and Walton 1983). Toward the east and north the bay's watershed is bounded by the Braden and Manatee Rivers, respectively, which flow into Tampa Bay. Uplands within the watershed occupy twice the surface area (80 sq mi) of open bay waters (40 sq mi) and are drained by the Palma Sola, Bowlees Creek, Whitaker Bayou, Hudson Bayou, and Phillippi Creek basins. The Phillippi Creek basin is the area's largest. Its impervious area increased from 15% in 1966 to 22% in 1988 and is expected to reach 24% by the year 2000. This trend is believed applicable for the watershed as a whole. Combined peak discharge of nonpoint sources to the bay area are about 13,560 cfs (for a 25 year, 24 hr event over the entire watershed) (Flannery 1988, Giovannelli 1988). Treated wastewater contributes another 15-25 cfs, and there are no industrial discharges of consequence.

Water quality is considered "good" for most parts of the bay[1]. In fact, all waters of the bay except for two small creek mouths are

[1]According to 305b summaries by the Florida Department of Environmental Regulation, using water quality (marine) and trophic state (aquatic) indices.

designated by the state as Outstanding Florida Waters, which provides for strict limits to degradation (Florida Department of Environmental Regulation 1986). Incomplete nutrient and other data suggest a general trend of improvement and a decline in salinity which has been most evident along the mainland shore. Urban stormwater runoff has been implicated as the cause for reduced salinities (Heyl and Dixon 1988). Areas of "fair" water quality include the bayside waters of Longboat Key, Little Sarasota Bay, and Phillippi Creek. Whitaker Bayou has fair to "poor" water quality because of stormwater and the City of Sarasota's municipal wastewater treatment plant effluent. An area of about 210 acres in the bay is directly affected by Whitaker Bayou discharges (Figure 2), and the area of indirect effects is probably ten times larger (Pierce and Brown 1986, Fortune 1985).

Direct and indirect effects of dredging and filling have not been evaluated with respect to water quality but are considered serious. Some beaches on all islands have been nourished at least once. Longboat and New Passes have been dredged for navigation purposes. The Intracoastal Waterway definitely caused several areas of bay-bottom to be spoiled; may be responsible for large losses of seagrasses in the north bay due to indirect turbidity effects; and is believed to have caused or enhanced closure of Midnight Pass (in Little Sarasota Bay, between Siesta and Casey Keys) (Sarasota County 1984). Major residential and commercial filling projects have been conducted on Bird, Lido, and Longboat Keys and City Island. These combined projects have altered circulation, tidal prisms, fine sediment budgets, inlet stability, bay transparency, and other parameters.

The primary producers of Sarasota Bay are phytoplankton, seagrasses, macroalgae, and wetlands (marshes and mangrove forests). The system is converting from a phytoplankton-dominated one with significant contributions (of carbon fixation, habitat, etc.) by the other producers, to a more simplified system dominated by phytoplankton without these other producers (Steidinger and Phillips 1988; Lewis 1988; Evans and Evans 1988). Sarasota Bay and nearby waters are regularly affected by naturally occurring dinoflagellate blooms known as red tides. These blooms originate far offshore but may be perpetuated by inshore nutrient enrichment. Red tides defaunate affected areas of the bay and inhibit tourism (Habas and Gilbert 1974). During summer months local phytoplankton blooms also kill fish in canals.

There are four seagrass species in the bay; all grow in water less than 6-7 ft deep. Between 1948 and 1979 there was a 54% decrease in seagrass cover along the eastern bay; a 65% loss around New Pass; and an 83% loss around Whitaker Bayou (Sauers and Patten 1981). Baywide losses are estimated to be 20-30 percent (Figures 3 and 4) (Steidinger and Phillips 1988). Causes of these losses are not definitely known, but mineral turbidity (from beach, inlet and ICW dredging) and organic turbidity (from STP effluents) are suspected. Marshes are naturally rare in the bay, but three species of mangroves grow along protected intertidal shorelines instead. Forests have been ditched for mosquito control and filled for upland development. Bay shorelines have been

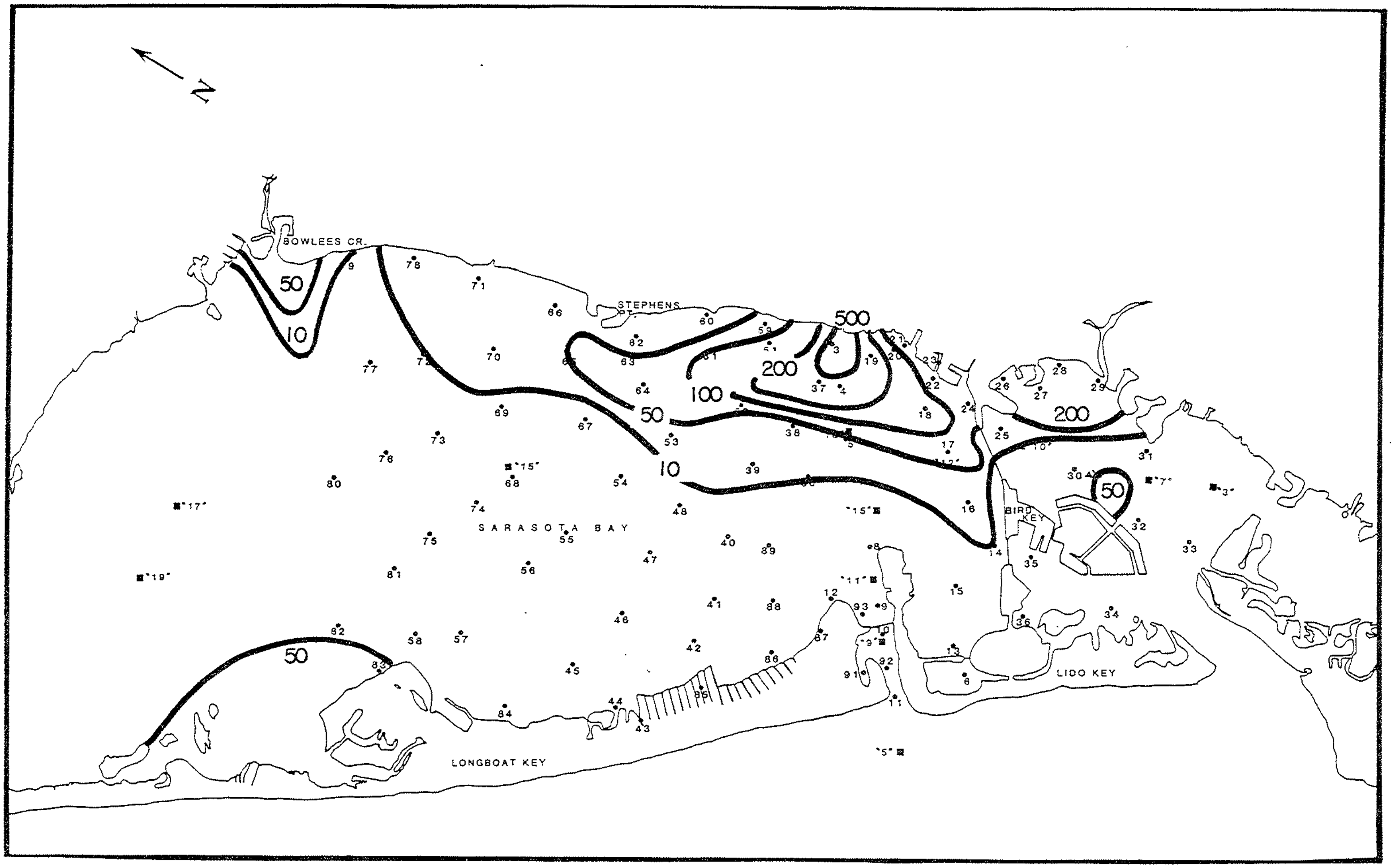

Figure 2. Isopleth map of coprostanol concentration, ng/g dry sediment.

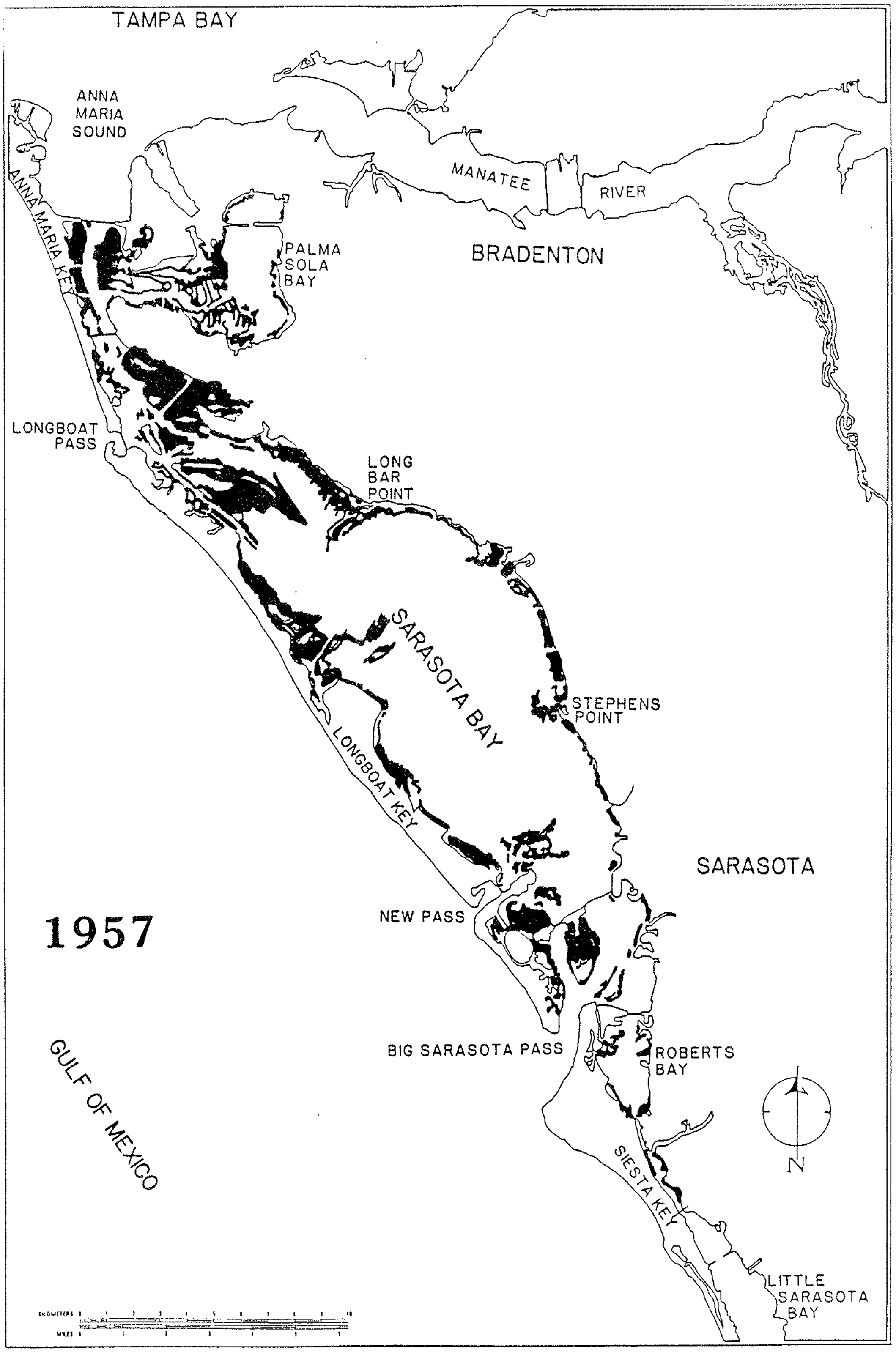

Figure 3. Seagrass distribution in Sarasota Bay in 1957 (from Lewis 1988a).

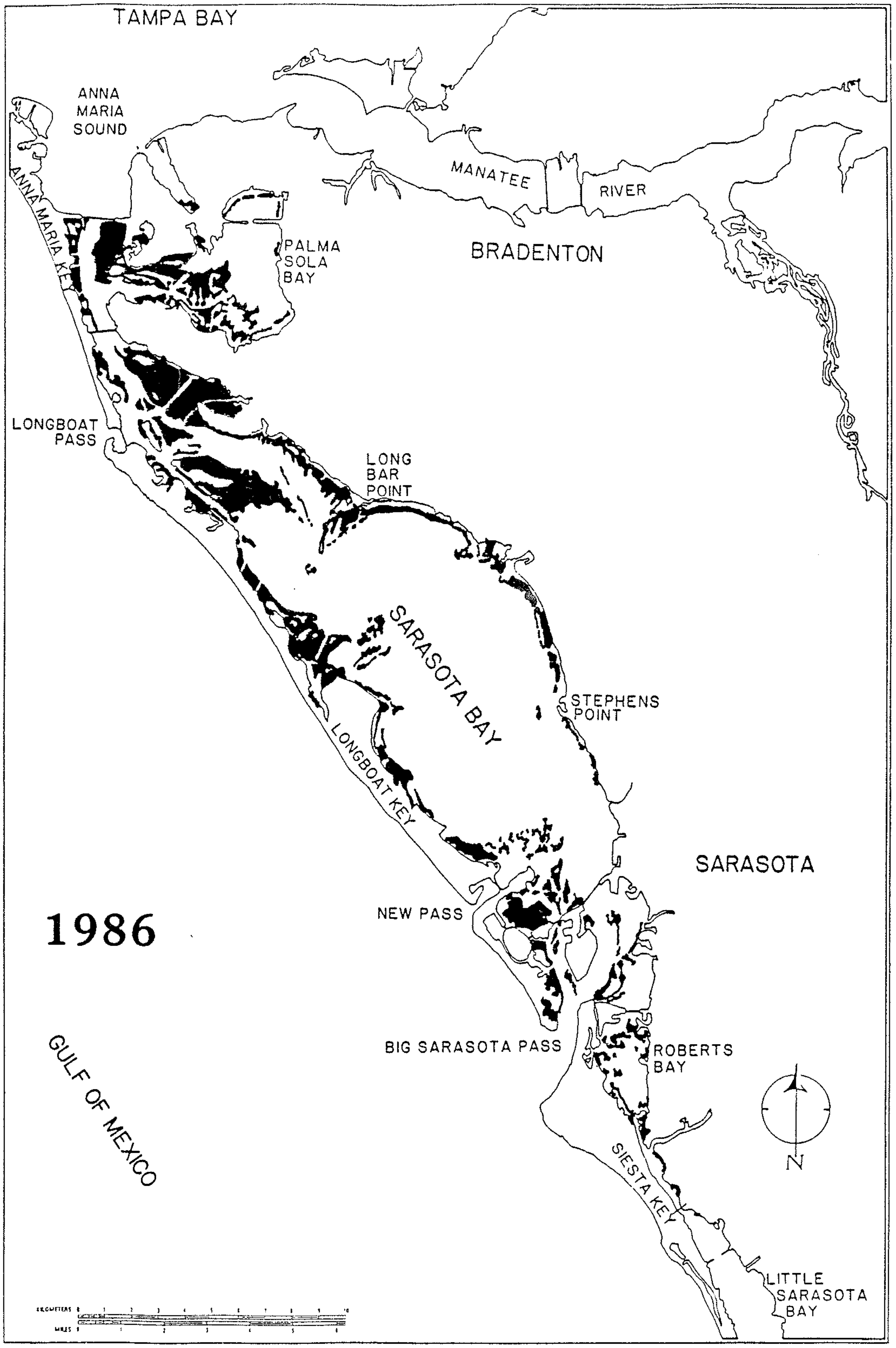

Figure 4. Seagrass distribution in Sarasota Bay in 1986 (from Lewis 1988a).

altered five-fold since 1948, mostly by bulkheading and invasion of two exotic tree species (Evans and Evans 1988).

Shallow, protected waters and once-widespread seagrasses supported an abundance of shellfish, sport and commercial fishes and unique vertebrate species. The shellfish resources of the bay were based on hard clams, oysters, and scallops (Estevez and Bruzek 1986). Scallops have disappeared from the bay, not having been landed commercially since 1964. Oyster landings ended in 1967 and hard clam landings ended in 1971, but both are still present in the bay, and there are probably enough hard clams to support a renewed harvest (Figure 5). Actual harvesting would be limited to 2 areas conditionally approved by the state for adequate sanitation (Palma Sola Bay[2]; Longboat Key bayside) unless pollution abatement allowed new areas to be opened.

Blue crab, stone crab, and (pink) bait shrimp are also taken from the bay (Stevely, Estevez and Culter 1988). There are 153 commercial blue crab permits and 180 stone crab permits issued for the two county area. Blue crab landings show marked, continual declines from 177,000 lbs/yr in the 1950's to about 30,000 lbs/yr today. Overfishing and habitat loss are believed responsible for the decline. Stone crab landings (of claws only) have increased from 6,400 lbs/yr to 24,000 lbs/yr over the same period due to increased demand. Bait shrimp landings have fallen precipitously, causing some to regard the fishery as completely collapsed -- but this may be an artifact of reporting (Stevely, Estevez and Culter 1988). Some commercial bait fishing currently occurs in the bay.

Sarasota Bay's finfish resources are mullet (commercial only), red drum and spotted seatrout (commercial and sport), and snook (sport only) (Edwards 1988). Mullet represents the largest fishery, with 2 to 6 million lbs landed annually. Whole fish are sent to local markets and manufacturers of fish products. Mullet roe has become a major byproduct, shipped to oriental markets (Haddad 1988). There may be some decline in mullet landings, but trends are indefinite. Spotted sea trout landings, however, have fallen six-fold from 300,000 lbs/yr in the 1950's, due to the destruction of seagrasses and probably overfishing. Red drum landings peak at about 200,000 lbs/yr and vary widely. In the 1980's, landings have been near 50,000 lbs/yr. The status of red drum has been declining throughout Florida, and last year seasons were adopted for their protection. Snook is a highly prized sport fish for which there are no landing data, but concern over their diminishing number has caused the adoption of seasons, plus limits to size, gear, and catch. Declines in snook stocks are attributed to habitat loss and overfishing (Edwards 1988).

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[2]Palma Sola Bay has been closed since 1981 because of excess coliform from runoff and septic tank leakage.

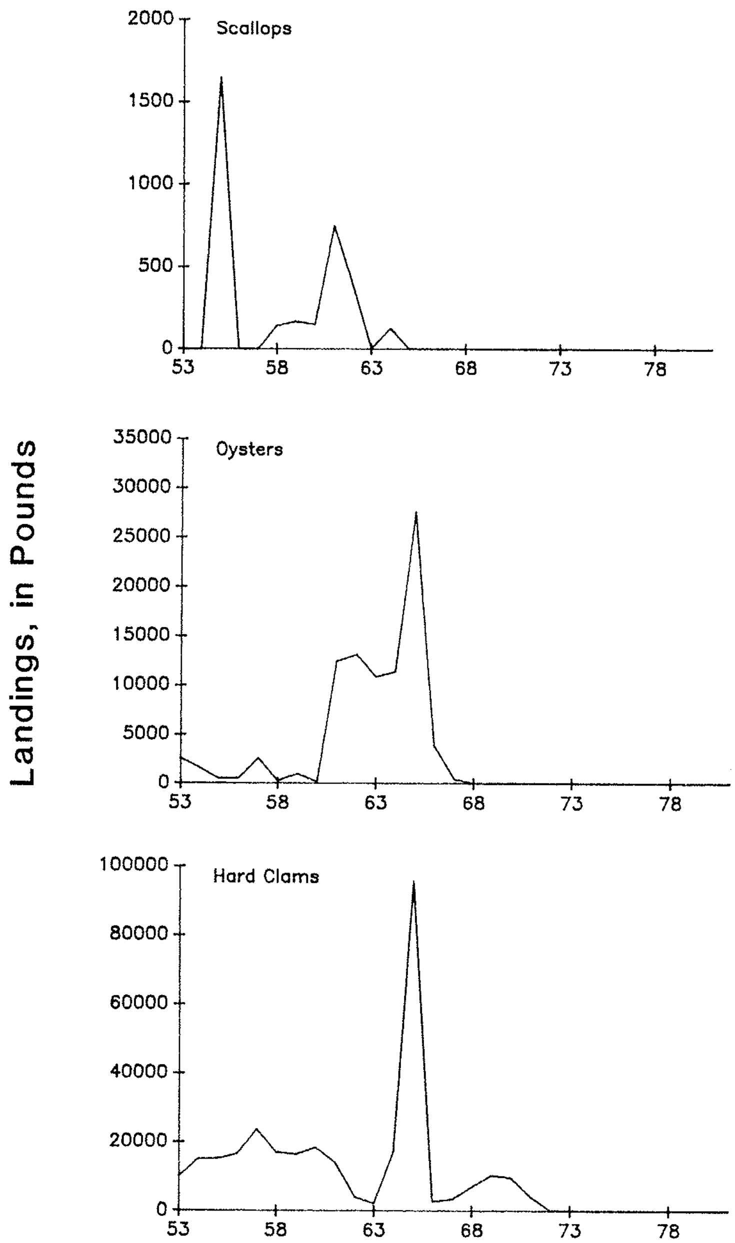

Figure 5. Sarasota County marine landings, 1953 to 1981.

Unique or important vertebrates in Sarasota Bay include the Atlantic loggerhead turtle, bottlenose dolphin, and West Indian manatee. Sea turtles use barrier beaches for nesting. In Manatee and Sarasota Counties combined, about 1000 nests are established per year (Mapes 1983-1986). Their success depends on storms, natural predators, and beach management practices. Dolphin populations have been studied longer in Sarasota Bay than anywhere else in the world (Wells 1988). Dolphins probably use the bay as a breeding ground and their numbers are stable, which is in marked contrast to manatees, an endangered species. Manatees occur in Sarasota Bay during summer months and use the bay as a corridor prior to the cold season. Between 25 and 50 manatees are believed to inhabit the bay on this basis (Patton 1987). The animals are threatened most by high speed boat traffic.

Sarasota Bay supports or enhances about 50 basic, water-dependent industries, institutions, and operations and about $20 million annually in overall payrolls (Daltry 1988). This direct benefit is augmented by an undocumented, indirect economic benefit and also by $115 million of economic value in the bay as a wastewater and stormwater receptacle. In addition, residential, waterfront property has an estimated value of $1.9 billion. Close proximity to the bay (less than 2% of the two county land mass) results in property tax equal to more than 19% of the total two county tax base (Daltry 1988).

Recreation constitutes the major use of the bay in the forms of boating, skiing, diving, surfing, fishing, sightseeing, and nature study. Sailing, especially regatta events, attract a national field of competitors. There are about 30,000 registered boats in the two county area, mostly pleasure craft. In 1985 there were almost 13 million beach use and saltwater fishing "occasions" in Manatee and Sarasota Counties. Such intensive contact and consumptive use represents a strong disincentive for pollution. A dozen conservation and environmental groups have a combined membership of nearly two thousand persons. The bay is used for educational purposes by one university, one community college, several high schools, and a marine program for youthful offenders.

History of Settlement and Resource Management

The Sarasota Bay area is urbanized in terms of its actual watershed, but the system is different than older, urbanized ones because it is recently settled and still has large areas of surrounding open space, farm land, and natural areas. The bay and basin have experienced only about 100 years of settlement. The period prior to World War II saw relatively little change in land or bay use, and environmental laws have been in effect for the past 15 years, so it was mostly during the period 1945-1975 that significant alterations to the bay and upland occurred. Today extensive areas of the watershed support land uses first put there (except for pasture or open range). This situation means that infrastructure is not as complex, well developed, or permanent as in northern coastal areas, so changes in land use, storm drainage, sewerage, or shoreline conditions may be easier or less expensive to accomplish.

The proximity of undeveloped interior lands may also facilitate projects which benefit the bay. Sewage treatment, for example, may be easier to provide at inland sites where gross densities are an order of magnitude lower than along the coast.

Today Sarasota Bay is more regulated than it is managed. Regulatory limits to projects with adverse impact exist at the federal and state level, but local regulation can be traced to public outcry in the 1960's over expansion of Bird Key and destruction of mangrove forests on the bay side of Longboat Key by a real estate development company. Local regulations were adopted to limit similar projects and to establish waters in the City of Sarasota as a marine park. Since then, the regional water management district has implemented rules controlling runoff and surface water management projects, and the state has (through the Department of Environmental Regulation - DER) enforced legislative acts addressing nonpoint and wastewater treatment levels. Most recently, in 1985 the Environmental Regulatory Commission designated Sarasota Bay as an "Outstanding Florida Water" (OFW), bringing into play the severest effluent regulations that are currently available in the state. Basically, OFW status requires that the DER issue no permit which directly lowers existing ambient water quality or indirectly degrades the OFW. However, the OFW status does not provide a management framework for the water body, even where water quality issues are concerned. It is merely a single regulatory criterion used in the issuance of permits.

There have been several steps leading toward a management program for Sarasota Bay. In 1985 the state legislature passed the Local Government Comprehensive Planning and Land Development Regulation Act, creating a new coastal management section in state law. The law was amended in 1985-86 and requires local governments to address specific plan topics; coordinate plans with neighboring governments; and be consistent with regional plans. Special effort must be made to ensure that "certain bays, estuaries and harbors that fall under the jurisdiction of more than one local government are managed in a consistent and coordinated manner". These requirements may set the stage for bay management, but revised plans alone will not contribute to a comprehensive program unless (1) the bay is viewed in its entirety by each plan; (2) the process leads to an institutional advocacy for the bay; and (3) each plan adopts the same language relative to the bay. These final measures are not required by state law, and the extent to which planning efforts would be redirected to achieve them remains to be seen.

Another significant advancement for Sarasota Bay's management can be traced to the 1982 Tampa Bay Scientific Information Symposium, at which existing knowledge about that bay was reviewed and evaluated for management purposes. The symposium led rapidly to a series of work groups culminating in an Agency on Bay Management within the Tampa Bay Regional Planning Council. The Agency adopted a management plan for Tampa Bay (Tampa Bay Management Study Commission 1985), and it is in its second year of implementation. Success in the Tampa Bay setting encouraged scientists and resource managers to meet in 1986 to assess the need for a management program for Sarasota Bay. The 1986 workshop recognized the value of such a program and endorsed a public symposium similar to that held for Tampa Bay (Estevez 1987). The symposium, known locally as SARABASIS[3] was held in 1987, and written proceedings will be available in 1988. Material from SARABASIS has been distilled for use by local planning agencies in preparing state-mandated comprehensive plans. Late in 1987 an estuarine seminar was held in Washington, D.C. on Tampa and Sarasota Bays under the sponsorship of the National Oceanic and Atmospheric Administration; SARABASIS materials also aided in preparation for that seminar and these proceedings.

In 1987 the 100th Congress reauthorized the Water Quality Act, which contained a part (Section 320. National Estuary Program) instructing the Environmental Protection Agency (EPA) to identify and protect nationally significant estuaries and to encourage development of comprehensive conservation and management plans. The Act states that the Administrator of the EPA is to give priority consideration to 12 coastal systems including Sarasota Bay. The Governor of Florida formally nominated Sarasota Bay to the EPA in May 1987, and in July 1987 Florida and EPA entered into a State/EPA agreement by which the EPA and DER continued the nomination process for inclusion of Sarasota Bay in the National Estuary Program (NEP). In July 1988 Sarasota Bay was designated by the Administrator of EPA as a component of the NEP.

PROBLEM IDENTIFICATION

A total of 120 resource management problems and issues were identified from historical references, workshop and conference proceedings, local government plans, and other sources. As used here, "problems and issues" are in reference to both the <u>causes</u> of management concerns (such as nutrient enrichment) and also the symptoms or <u>effects</u> such concerns can take (such as algae blooms). In most cases the problems can be identified but not described or detailed. Indeed, the inability to understand the specifics of an issue contributes to the problem.

Problem descriptions can only be developed once they are ranked by importance and studied in greater depth. This process is part of a NEP Management Conference but would also occur in a non-federal management initiative. In either case, key questions to address in the process of problem review will include (1) is the perception of the problem accurate; (2) does the problem influence a large part of the estuary; (3) can the likely cause of the problem be identified; and (4) is it feasible to correct the problem?

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[3]for Sarasota <u>B</u>ay <u>A</u>rea <u>S</u>cientific <u>I</u>nformation <u>S</u>ymposium.

The 120 individual problems and issues are organized in Table 1 into a few condensed sets and arranged with respect to management complexity. Criteria used for the sets and arrangements were (1) overlap with other problems; (2) extent to which problem concerns the cause of many other problems; (3) responsiveness to local needs; (4) the degree to which a problem is unique to the area, or is of national significance but may be easier to address in the Sarasota Bay area because of other circumstances; and (5) the probable role of federal, state and/or local government involvement.

The sets are arranged from most federal involvement to most local involvement in Table 1. No priorities are implied by the order of sets within each level. Sets are meant to be organizing concepts around which management projects can develop, assimilating a number of specific, related problems in the process. Not all specific problems can be addressed by the sets described below, but refinement of the approach should improve such coverage.

SUMMARY AND CONCLUSIONS

Sarasota Bay was identified in Section 320 (National Estuary Program) of the Water Quality Act of 1987 for priority consideration as an estuary of national significance. The bay is the only Florida system so identified and the only subtropical one. It is a very small, relatively clean system which ranks poorly where estuarine area or number of major problems are considered. On the other hand, it ranks highly in terms of preservation need and in terms of its vulnerability because of its small size. It is also distinguished by having more problems resulting from development and overuse than from pollution, especially the many forms of pollution which plague northern estuaries. In this regard, Sarasota Bay represents an excellent setting in which to develop and evaluate management tools focusing on development and overuse impacts. The small size of the bay is an added advantage in such a context. Overall, Sarasota Bay offers the opportunity to address nationally significant problems such as integrated beach/inlet/channel maintenance, nonpoint source control, habitat loss, and sea level rise. Results from a Sarasota Bay study would also be transferable to similar lagoons, bar-built estuaries, and small embayments throughout the gulf and south Atlantic coastlines. Extensive tourism and seasonal residence of northern and midwestern visitors would extend the benefit of a local bay educational program to areas of the nation lacking bay management programs.

Table 1. continued.

Table 1. Major Problem Sets for Sarasota Bay, in Order of Management Complexity. No priorities are intended by the order of listed items.

A. Federal, state, regional and local participation

These problem sets would benefit from a significant level of federal participation in addition to state, regional and local involvement.

1. Stormwater runoff. The watershed is mostly developed and programs to retrofit existing developed areas will be complicated and costly. Stormwater is a serious problem in the bay, but improvements to runoff management systems should be measurable in terms of bay resources and values. Response to runoff projects will be easier to detect than in systems facing multiple stresses. Studies of runoff in tidally affected creeks would be nationally significant.

2. Beach/inlet/channel management. At present, beaches are (or can be) nourished by federal or state or local agencies, or private parties. Inlets may be dredged for navigation, beach spoil, or both goals. Approach channels and the Intracoastal Waterway are managed with minimal local role. Impacts of these combined, interrelated activities are significant and tools developed to manage these impacts would be nationally useful. The opportunity to address these problems may be unique to the bay area, if they are not identified as important resource management issues in other priority estuaries named in the Water Quality Act of 1987.

3. Habitat creation and restoration. A number of specific problems concern habitat. The status, restoration, and preservation of seagrasses is the most important habitat issue in the bay. The special problem of intertidal habitat in Sarasota Bay is the lack of suitable, naturally occurring sites. Impaired habitat can be restored, but significant habitat gains will be more complicated to justify, design, implement and evaluate. A federal involvement will be needed to develop habitat creation projects in urban settings where potential space is limited. Such projects would be nationally useful, however, as models for similar situations.

4. Sea level rise (SLR). Federal involvement in this issue far outdistances state activity despite Florida's special relation to the sea. The development of a meaningful assessment of SLR impacts for Sarasota Bay would help the

Table 1. continued.

area in terms of research and contingency plans and also represent a national demonstration project for community-level participation (Figure 6). The issue is also relevant to turbidity, habitat, stormwater and other major problems.

B. State, regional and local participation.

These problem sets are probably amenable to solution by non-federal governments if coordinated in a management conference framework. Federal participation could enhance specific work elements through application of national expertise.

1. Coordinated monitoring. This set includes problems of data retrieval, synthesis, and application to management issues, and also adjustments and additions to water quality and other environmental samplings in the bay. A relevant model may be the SWIM[4] data compilation project underway in Tampa Bay.

2. Shellfish sanitation. Conditionally approved areas are closed on intermittent or continuing bases. Harvests in other areas are prohibited due to runoff, or prohibited by default because the area has not been evaluated. A program to reopen, open, and study these areas is needed.

3. Fisheries assessment, management and restoration. This problem set addresses the unknown status of shellfish and finfish stocks; recreational effort; local laws; allocation disputes; and habitat needs. Protection of stone crabs and bait shrimp, and restoration of scallops deserve special effort.

4. Access improvements. Taken collectively, problems of scenic, beach, boating, and passive access form a set of significant impediments to full use of the bay. Access builds a popular constituency for the bay which creates support for other management programs but will require state and regional effort to accomplish during initial project stages.

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[4]Surface Water Improvement and Management Act of 1987.

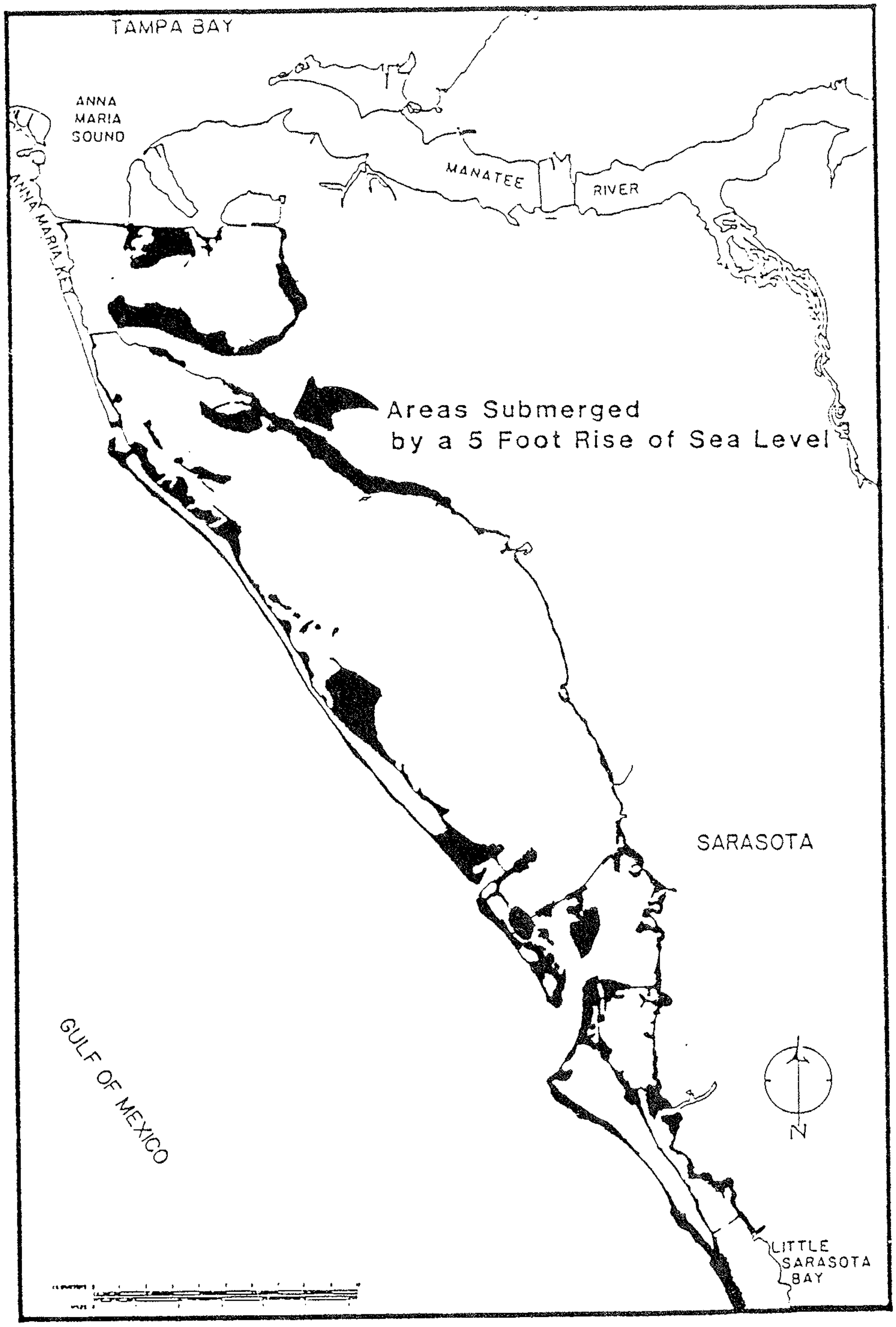

Figure 6. Shorelines of Sarasota Bay sumbmerged by a 5-foot rise in sea level.

Table 1. continued.

C. Regional, local and private participation

These sets are probably amenable to solution without extensive commitment of federal or state resources other than their role in providing a management framework. As in the previous case, federal or state involvement would significantly enhance specific work elements.

1. Coordinated planning. It does not appear that coordination requirements of state planning laws will be met for Sarasota Bay, much less their codification in capital improvement, land use, or other implementation measures. Emphasis needs to be placed on adjoining governments and specific consistency between regional plans.

2. Plans for geographic areas of particular concern (GAPC). This set recognizes the many site-specific management needs occurring around the bay, and would create a mechanism within the larger conference process to develop GAPC plans with goals, plans, studies, etc. tailored to each area's particular needs. The GAPC approach is an approved part of coastal zone management programs at the state level, but has not been used widely at the regional or local level.

3. Educational programs. The lack of general and specific educational programs is one of the most often cited problems regarding Sarasota Bay. Educational programs, public participation, and related activities are central to all phases of bay management but can be handled adequately by regional and local governments. One nationally significant aspect of a Sarasota Bay educational program would be the extensive involvement of tourists and seasonal residents. These persons would return to their northern homes with conservation knowledge applicable to problems in distant neighborhoods.

4. Boat traffic improvements. This set addresses wake erosion, manatee protection, seagrass signage, multiple uses, bridge operation, marina practices, and related problems. Access and use cannot be formally restricted, so policies and procedures related to boating must be developed to accommodate a growing boater population.

Table 1. continued.

D. **Local and private participation**

With the incentive and technical support of a management conference, local governments and private citizens should be able to make significant contributions to the health of the bay in several areas.

1. Shoreline protection and management. A uniform, rational and ecologically beneficial approach is needed by local governments and waterfront landowners to remove seawalls, optimize dockage, enhance native vegetation, and control litter. (This set refers mostly to bay shorelines but could be addressed in conjunction with gulf beach projects.)

2. Control of exotic tree species. Encroachment of natural, mangrove-vegetated shorelines by Brazilian pepper and Australian pine, and, to a lesser extent, ornamental vegetation can be effectively prevented through a cooperative program involving local governments and citizens.

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PERSPECTIVE ON MANAGEMENT OF TAMPA AND SARASOTA BAYS

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INTRODUCTION

A number of local governments and regional associations of local governments in Florida and other states have experienced problems similar to those in Tampa and Sarasota Bays arising from a lack of coordinated management of estuarine resources. The management experience of Tampa Bay is particularly relevant to both bays in terms of their natural systems and the pressures and demands placed on the system. Although similar to each other in many ways, the management histories, opportunities, and challenges of Tampa and Sarasota Bays are different.

HISTORIC MANAGEMENT ATTEMPTS

Tampa Bay

There have been numerous attempts over the past 25 years to establish a committee or commission to examine the problems of Tampa Bay. The Florida Legislature created the Tampa Bay Conservation and Development Commission in 1970 in response to growing public concern about the environmental degradation of Tampa Bay. This Commission was composed entirely of local legislators and other elected officials and was charged with determining the public interest in Tampa Bay, and to determine the effects of further dredging and filling on navigation and fish and wildlife resources in the bay. The Tampa Bay Conservation and Development Commission, however, never met.

In 1982 the first symposium on Tampa Bay was held at the University of South Florida. The Tampa Bay Area Scientific Information Symposium (BASIS) lasted four days and involved topical presentations by 50 invited speakers. Major conclusions of the symposium were that: 1) Tampa Bay can and should be comprehended and managed as a single ecological system; 2) the bay is remarkably resistant to environmental challenges; 3) a clear pattern of decline is evident in some measures of ecological condition; and 4) the management needs of Tampa Bay are relatively clear and, if implemented in a comprehensive and baywide basis, would result in tangible improvements tc the bay and its usefulness to people (TBRPC 1985).

It was further concluded that the state and federal regulatory agencies, local governments surrounding the Bay, and an array of industries and user groups often carry out their respective activities independently. The effect of bay management by a multitude of overlapping and often conflicting interests and jurisdictions had contributed to a number of environmental and growth management problems in the bay area (TBRPC 1985).

In May 1982, the Tampa Bay Regional Planning Council established the Tampa Bay Management Study Committee. The Committee was charged with the task of identifying critical bay management problems and evaluating potential solutions for those problems. By December 1983, the Tampa Bay Study Committee had identified 40 specific bay issues. Because of the large number and complex nature of the issues affecting Tampa Bay, however, the Committee did not reach a consensus regarding the approach to the management of the bay.

As a result, a 15 to 20 member interim steering committee provided for effective representation from a wide range of Tampa Bay's business, environmental, and industrial interests, as well as from the local regulatory agencies having jurisdiction over the bay. During its six-month tenure, the steering committee concentrated primarily on a comprehensive survey and review of all entities having management responsibility for Tampa Bay, with the objective of documenting all major jurisdictional gaps and overlaps (TBRPC 1985).

The conclusions reached at the BASIS conference underscored the importance of approaching estuarine management at the ecosystem level. In recognition of the need for a credible and structured form within which to pursue a more unified management scheme, the Florida Legislature created the Tampa Bay Management Study Commission under a special act adopted in 1984. The Commission received a one year mandate to recommend a bay management plan and work program to address priority bay management issues (in conjunction with ongoing efforts by the U.S. Congress, the U.S. Fish and Wildlife Service, state agencies, port authorities and other regulatory entities) for submittal prior to the 1985 legislative session.

In its final report entitled Future of Tampa Bay, the Tampa Bay Management and Study Commission recommended to the Florida Legislature the establishment of a coordinating and advisory committee as an interim solution to the management inconsistencies plaguing Tampa Bay. Although no legislative action was taken, the Tampa Bay Regional Planning Council (TBRPC) created the Agency on Bay Management in June 1985 as an advisory committee of the TBRPC.

Sarasota Bay

The history of resource management in Sarasota Bay has not been as extensive as that for Tampa Bay. The first true effort was a September 1986 workshop organized by Mote Marine Laboratory. At the workshop approximately 60 officials and staff members from Sarasota and Manatee Counties, local scientists, and educators gathered to discuss the management needs of Sarasota Bay and how these needs might be met through the state-mandated comprehensive planning process (Estevez 1988). The workshop participants unanimously agreed on the need for an inter-local bay management program in place of the management void that existed. As a necessary step in the development of a bay management program, the workshop participants endorsed the concept of an intergovernmental symposium on Sarasota Bay, which would serve to coalesce relevant scientific and demographic information about the bay and to examine similar management processes undertaken for other estuaries (Eckenrod 1988).

The Sarasota Bay Area Scientific Information Symposium (SARABASIS) was held in April 1987. The symposium lasted for two days and coincided with field trips, special exhibits, and other activities related to Sarasota Bay. Sessions were held on a number of topics ranging from geology of Sarasota Bay to the biology of marine animals in the bay. Other sessions involved the history, economics, public use of the bay, and bay management. The public was invited to provide input on goals of management for Sarasota Bay. Symposium sessions were aimed at a general audience, whereas the written record will be designed as a reference document of use to planners, educators, and scientists. Proceedings of the symposium are in preparation. The interest generated by SARABASIS stated clearly that a conference reviewing scientific and other information was a timely and valuable exercise, and that the management needs for Sarasota Bay have been overlooked.

EXISTING BAY MANAGEMENT EFFORTS

Tampa Bay

Both historically and currently, Tampa Bay constitutes the central geographic feature most responsible for the shipping, industrial development, aesthetic and recreational values that encompass the overall attractiveness of the region to new residents. The management of Tampa Bay is fragmented among a multitude of federal, state, and regional regulatory agencies, as well as seventeen local governments (three counties and fourteen municipalities) bordering the bay. Management is accomplished through the uncoordinated implementation of various monitoring, permitting, and regulatory programs. Under the existing management framework, jurisdictions are often overlapping; interests are often conflicting; and no one agency has overview authority for the bay or manages it as a holistic natural resource. As a result, management of Tampa Bay has been both wasteful and ineffective (TBRPC 1987).

With the creation of the Tampa Bay Management Study Commission and the TBRPC's Agency on Bay Management, however, there has been an attempt to implement a bay management program in a unified, holistic manner. The 45 member Agency includes membership from the following groups:

- o The Florida Senate representing the Tampa Bay region;
- o The Florida House of Representatives representing the Tampa Bay region;

- The Tampa Bay Regional Planning Council;
- The Southwest Florida Water Management District;
- The U.S. Army Corps of Engineers;
- The National Marine Fisheries Service;
- The Florida Department of Natural Resources;
- The Florida Department of Environmental Regulation;
- The Florida Department of Community Affairs;
- The Florida Department of Transportation;
- The Florida Marine Patrol;
- Environmental interests in the Tampa Bay region;
- Commercial interests in the Tampa Bay region;
- Industrial interests in the Tampa Bay region;
- Science and academic interests in the Tampa Bay region;
- Recreational interests in the Tampa Bay region;
- Hillsborough, Manatee, and Pinellas Counties representatives;
- Tampa, Manatee and St. Petersburg Port Authorities;
- The Cities of Tampa and St. Petersburg;
- Two other municipalities bordering Tampa Bay, and
- The Tampa Bay region at large.

Sarasota Bay

Sauers (1988) and Estevez (1988) suggest that Sarasota Bay should be considered as unmanaged rather than mismanaged. Major decisions which affect the resource value of Sarasota Bay have historically resulted in a decline of its once pristine quality. Decisions to fill submerged bottom lands for residential development, discharge wastewater, dredge the Intracoastal Waterway, and accelerate input of large quantities of stormwater runoff have been made without adequate technical information regarding the consequences of such actions. Future decisions, such as construction of a cross-bay bridge, the retrofitting of urban stormwater and wastewater systems, or how to cope with rising sea level also have the potential to be made without close ecological scrutiny (Sauers 1988).

Formerly, development decisions in and around the bay were based on intuition tempered somewhat by the lessons learned through mistakes which wasted natural resources. Now, faced with the evidence of past mistakes and the realization that we can no longer move to escape such damage, a more formal approach to decisions concerning the development and natural resources is considered necessary. It is imperative to allocate coastal resources before the rapid pace of development eliminates the most desirable options and results in irretrievable and irreversible commitments of these resources (Sauers 1988).

Estevez (1988) reported that natural resource management is most effective when the resource is viewed as a single ecological unit. Sarasota Bay is not managed as a system at the present time, however. Decisions are made on a case specific basis without the benefit of experience from nearby cases or an overall strategy or goal for the bay. No system for bay management presently exists. Consequently, Sarasota Bay should be considered unmanaged rather than mismanaged.

Estevez (1988) further stated that another strong argument for viewing Sarasota Bay as an unmanaged resource is the lack of an institutional advocacy. There is no office or person at any level of government presently charged with planning for the whole bay and representing that view as local decisions are made. It is one thing to have a baywide outlook or plan; it is quite another to have a system in place which provides for the routine consideration of the plan and a speaker for the bay (Estevez 1988).

Eckenrod (1988) reported that, in addition to reviewing the accomplishments of the Tampa Bay management effort, it is of value to managers of other coastal resources such as Sarasota Bay to examine what factors may have kept the Tampa Bay management effort from being more successful than it has been. He further suggested that factors which have impeded the progress of the management effort include: 1) the need for cohesiveness and greater simplicity; 2) the lack of full-time staff; and 3) limited involvement of the private sector.

IS THERE A FUTURE FOR BAY MANAGEMENT?

It is an interesting paradox that, although all of the interest groups of both Tampa and Sarasota Bay desire an effective management program, none truly exists. The Tampa Bay community has had the longest history of bay management exercises and still is unable to demonstrate an effective management scheme. The Tampa Bay Management Study Commission suggested that a Bay Management Authority would be the best mechanism. Although politically unpalatable at this time, it remains an option.

The Agency on Bay Management is close to actually being a management program. To date, the Agency on Bay Management has served as a useful forum for discussion of information related to bay management issues. The Agency has been very successful in facilitating communication between responsible agencies and affected interests; providing coordinated recommendations regarding environmentally sensitive projects within the Tampa Bay watershed; establishing a vital link between Tampa Bay interests and the state legislature; and implementing the recommendations set forth in the Future of Tampa Bay.

However, the Agency is comprised of volunteer members and has no regulatory authority and no delegated responsibilities for the management of Tampa Bay as a single, holistic system. The Agency is also stymied by severely limited funding, and is staffed by TBRPC employees on a part-time basis. Due to these constraints, the Agency is therefore not the final answer for bay management needs of Tampa Bay at this time.

During the 1987 legislative session, the Florida Legislature passed the Surface Water Improvement and Management (SWIM) Act, the intent of which was to initiate the restoration and protection of surface water bodies on a statewide basis. The legislation mandated that the State's five Water Management Districts implement the program. The State also created the SWIM Trust Fund to which appropriations would be made to support the program. The first year's appropriation of $15 million was allocated for six priority water bodies, four of which were estuarine waters (including Tampa Bay). The Southwest Florida Water Management District has, therefore, been thrust into the bay management picture by the legislation.

The District has all or part of 16 counties and approximately 10,000 square miles within its jurisdiction, which includes the southwest coast of Florida. In recent years, the District has expanded its traditional role of helping to resolve flooding problems. It now performs regulatory functions for well construction, consumptive use, surface and stormwater management, and aquatic plant management. Surface water and stormwater discharge permitting acts to regulate the impact of new construction on water quantity, water quality, wetlands or other natural resources. The District historically has had little involvement in estuarine areas; however, it now has been given the responsibility for improving Tampa Bay.

The legislation instructs the District to designate priority water bodies, and to prepare and implement restoration and management plans for these water bodies. Although Tampa Bay has been identified in the legislation, it is not inconceivable that the District may become involved with many other estuarine areas (such as Sarasota Bay) within its jurisdiction. It also is not inconceivable that the water management district may be the appropriate mechanism for effective bay management, since the District now:

1. has a State mandate to become an active participant in bay management;

2. already has regulatory responsibilities for surface water permitting and may soon be delegated additional permitting responsibilities;

3. has taxing authority and can generate the revenue.

Sarasota Bay has not had the checkered history of management attempts and, consequently, does not have the background information that typically would be generated through the management development process. This is not to say that nothing is known about the bay; in fact, much is, but this knowledge has not been used to develop a comprehension of the bay as an ecosystem. Without information of this type, the corrective or restorative functions of a management system cannot operate.

Estevez (1988) noted that goals must exist for a resource management system to operate. Such goals should be defined for and by the public and be practical, verifiable, and meaningful. Practical means achievable with existing technical skills, rather than political or legal feasibility. Verifiable means that improvements occur as a result of management which the lay public can perceive through everyday use of the bay. Meaningfulness if defined relative to improvement of the bay compared to its previous condition.

Goals for Sarasota Bay as a whole do not exist now, except insofar as regional plans contain general language applicable to all of the region's bays. However, Sarasota Bay is unique by its division into two regional planning areas, so even the existing regional plans agree only by coincidence where the bay is concerned (Estevez 1988).

The hope for a management program for Sarasota Bay should not be abandoned. In 1986, the 99th Congress passed a reauthorization of the Water Quality Act, which drew an executive veto after the session closed. In 1987, the 100th Congress overrode a second veto to authorize the Act as originally drafted. An element of the Act (Section 320, National Estuary Program) identifies nationally significant estuaries threatened by pollution, development of overuse; promotes comprehensive planning for these estuaries; encourages the preparation of management plans; and enhances the coordination of estuarine research.

Governors may nominate estuaries of national significance to the Administrator of the Environmental Protection Agency and request a management conference to develop a comprehensive management plan for the estuary. It is important to note that the federal program is called a management conference, but in fact involves much more than a conference per se. Special panels are convened as part of the process to set policy, interpret data, collect new information and produce educational programs. The conference should not be confused with the Bay Symposium described earlier in this paper.

The act intends that the Administrator give priority consideration to several estuaries across the nation, including Sarasota Bay. The principal purposes of the management conference are to collect existing data and assess trends in water quality, natural resources and uses of the ecosystem; develop relationships between point and non-point loadings of pollutants to water quality and natural resources; and develop, implement and monitor a comprehensive plan that identifies priority corrective actions.

Participants in the management conference are specified and include federal and state governments, public and private educational institutions and the general public. The conference has up to five years to develop a plan which then can be implemented with state and federal grants.

SUMMARY AND CONCLUSIONS

The experience of other bay management programs supports the view that the extra effort expended to develop a bay management plan is offset by the extra benefits which result. The management objectives for Tampa Bay and Sarasota Bay are quite similar, however, the systems are inherently different. That fact notwithstanding, both bays must be comprehended and managed in a holistic manner. The involvement of a myriad of agencies at all levels of government speaks to the need for consolidation, with few agencies, preferably one, having comprehensive jurisdiction. Anticipated solutions must be implemented with direct planned actions and not operate under a crisis-management approach. Currently, decision-making is the responsibility of many disparate groups. These groups must communicate and interact with each other to promote a proactive rather than reactive approach.

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